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for Educators in the Fields of Engineering and Allied Sciences

GENERAL MOTORS TECHNICAL CENTER DEDICATION ISSUE

On the Dedication of the Technical Center

ALMOST eleven years ago, on July 24, 1945, during the final days of the War in the Pacific, General Motors announced plans for a great new Technical Center to be erected on the outskirts of Detroit.

Possibly the most ambitious project of its kind ever launched, the General Motors Technical Center was conceived as a means of assuring in the postwar years continued progress in research, engineering, and design, with the objective of a steadily advancing standard of living and more and better job opportunities.

Work on the first building at the Center got under way in 1949. The last of the 25 structures currently contemplated was completed this past winter, and final landscaping of the 320-acre site was accomplished this Spring. We will dedicate the Center this month.

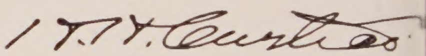
At present 4,000 scientists, engineers, designers, technicians, and other personnel are working at the Technical Center. They comprise the central staffs of General Motors in research, advanced engineering, styling, and process development. Their work ranges all the way from pure science to finding better things to make and better ways to make them.

I do not believe I exaggerate when I say that the General Motors Technical Center is unique with respect to size, scope, and the vision behind it. There is not another facility like it in the world. Nor is it too much to say that the Center represents a vital national asset.

It is vital to the continued progress of our country in peace. It is also vital to national defense. Some defense projects are in progress there even now, but, more importantly, it exists as a magnificent resource which can always be called on in time of need.

It is my hope that the more than 5,000 leaders in the professions and in business who will gather for the dedicatory ceremonies will carry away with them this broad concept of what the Technical Center stands for, as well as a clearer understanding of General Motors contributions to and role in the economy of our country.

I also hope that the men and women working at the Center will derive from the ceremonies inspiration that will enable them to contribute of their best to the future progress of General Motors and of the nation.



Harlow H. Curtice
President,
General Motors Corporation

THE COVER

This issue is designed to commemorate the formal dedication of the new General Motors Technical Center. The cover photograph by Walter Farynk of General Motors Photographic symbolizes the thought that progress through science and engineering is simply a better understanding of nature's elements and the natural laws which govern them.

- ● Photographs by: Ezra Stoller
- ★ Photographs by: General Motors Photographic

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GENERAL MOTORS
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The GENERAL MOTORS ENGINEERING JOURNAL is published every other month by the Educational Relations Section of the Public Relations Staff, General Motors Corporation, and is intended primarily as a medium for presenting to the field of engineering education the results of General Motors research and engineering developments both in the product and production fields.

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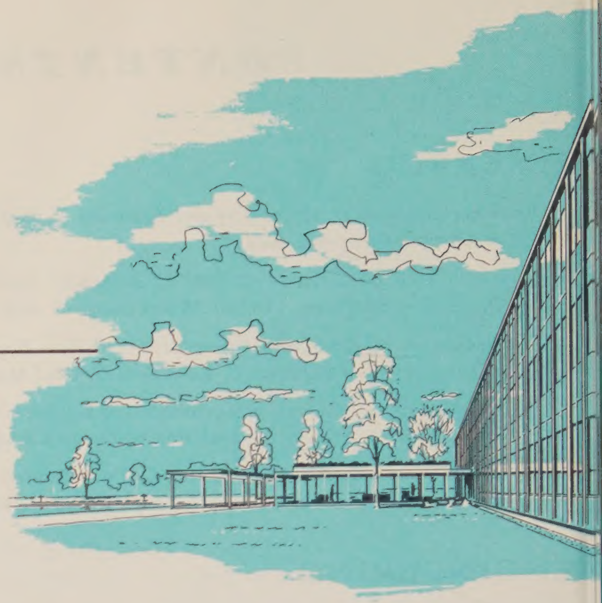
Research in General Motors



THE future is our business. This is the fundamental, guiding philosophy of research in General Motors. The eight new buildings of the Research Staff are the visible evidence of General Motors confidence that the future will be better than the past (Fig. 1). It is the investment which must be made now to assure us the new and improved products and processes necessary for an expanding economy.

It is in the tradition of science first to observe, then to understand, and finally to utilize the forces of nature. Man has been doing this since the dawn of history, but at one time discoveries were made in a "hit or miss" manner by lone investigators poorly supplied with information and equipment. We have now learned to bring trained scientists and engineers together in such well-equipped laboratories as are at the Technical Center, to make discoveries and develop new ideas. This is an important new conception in our modern economy which has resulted in greatly accelerated technological progress.

General Motors has supported a research organization for over 40 years. Research discoveries and developments have contributed to all the products of GM's manufacturing Divisions. Our automobiles, Diesel engines, household appliances, locomotives, and jet engines have all depended upon a continuous research program for their constant improvement.

The Research Staff is the one organization in General Motors that deals solely with fundamental, long-range research. Its scientists and engineers are concerned with projects that continuously explore the future.

The program is divided into fundamental scientific research, long-range engineering research, and advanced engineering development. In the new Research Staff facilities at the Technical Center emphasis is placed on basic projects which, when successful, will result in technological improvement.

The Research Staff has a two-fold responsibility to General Motors management and to the manufacturing Divisions. First and foremost, we discover and develop fundamental information which will become the basis for the new products of tomorrow. Second, our specialized personnel and facilities are available for use by the Engineering Departments of the various GM manufacturing units should they choose to use them.

When you analyze our basic problems, they fall into two broad categories: energy and materials.

Energy

It is estimated that our energy requirements in the United States 25 years from now will be about double those of today. This presents a tremendous challenge to the Research Staff and becomes the reason for our extensive programs in fuels and power plants. In 1955 General Motors produced almost one billion horsepower in automobiles alone. It is no wonder that we are so vitally interested in the future sources of energy. Liquid petroleum fuels are the mainstay of our products today. It is possible that in the future uranium and thorium may be just as commonly understood words as gasoline and fuel oil are today.

Therefore, large groups in the Research Staff devote their skills and experience to means of producing power more efficiently.

Gasoline engines, Diesel engines, jet engines, free-piston engines, and gas turbines and the fuels which they burn all provide promising projects for better power plants in the years ahead.

How we can make the best use of atomic energy in industry and transportation of the future becomes our newest long-range problem. One pound of uranium, U-235, has as much energy as 1,300 tons of coal which is a ratio of 1 to 2,600,000—*this* is the incentive.

Materials

Our second big problem is materials. At present it takes 18 tons of material per year to keep an American citizen in his present standard of living. This adds up to the astronomical figure of over 2½ billion tons of material per year for the United States alone. Last year (1955) General Motors alone produced about 7½ million tons of automobiles.

We support a never-ending search for new materials, new processes, new alloys, and new methods of fabrication. A part of this program is a group of engineering projects aimed at increasing the fatigue life of parts and utilizing materials more efficiently.

By Dr. LAWRENCE R. HAFSTAD
Vice President
in charge of
Research Staff

But in all the work of the Research Staff the most important single factor is people. Modern facilities, instrumentation, and scientific equipment are necessary in today's research establishment, but it is the people who make the discoveries and perform the experiments (Fig. 2). It takes men with training in many branches of science and engineering —all of whom focus their particular talents on the problems. These are reinforced by laboratory technicians, skilled mechanics, and other craftsmen.

The trained people who make up the Research Staff form a well-organized team to assure General Motors of continued advances in the future. The thousands of hours spent each year on the problems of the future are the insurance that tomorrow's products will be better and more abundant than those of today.

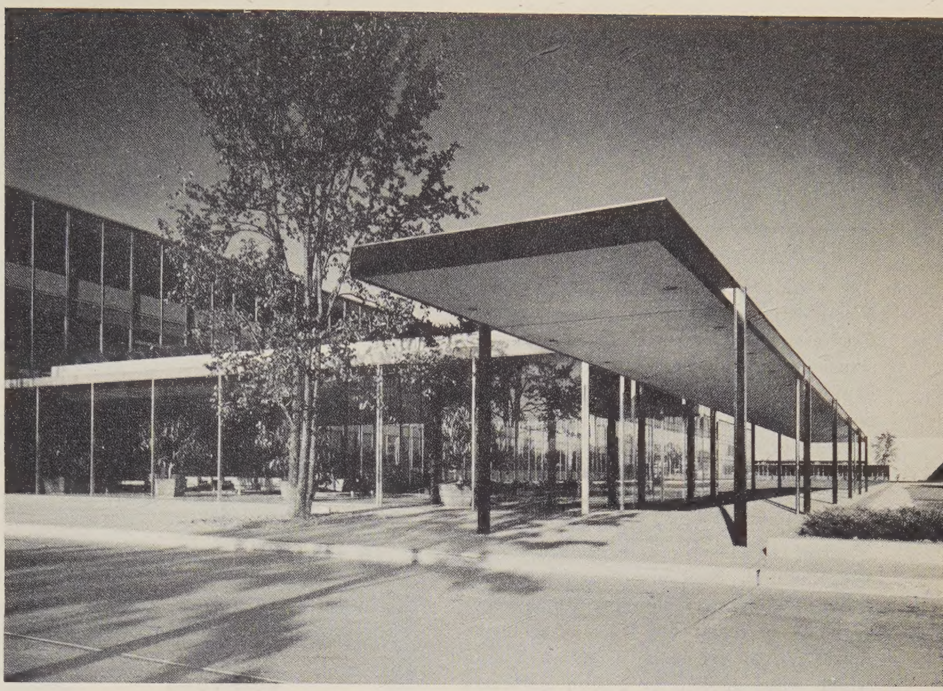


Fig. 1—The lobby entrance to the Research Staff Administration Building is essentially a glass-enclosed patio overlooking a 22-acre artificial lake at the General Motors Technical Center. The Administration Building is a three-story structure containing offices, laboratories, library facilities and meeting rooms. Other Research buildings are grouped behind the Administration Building.

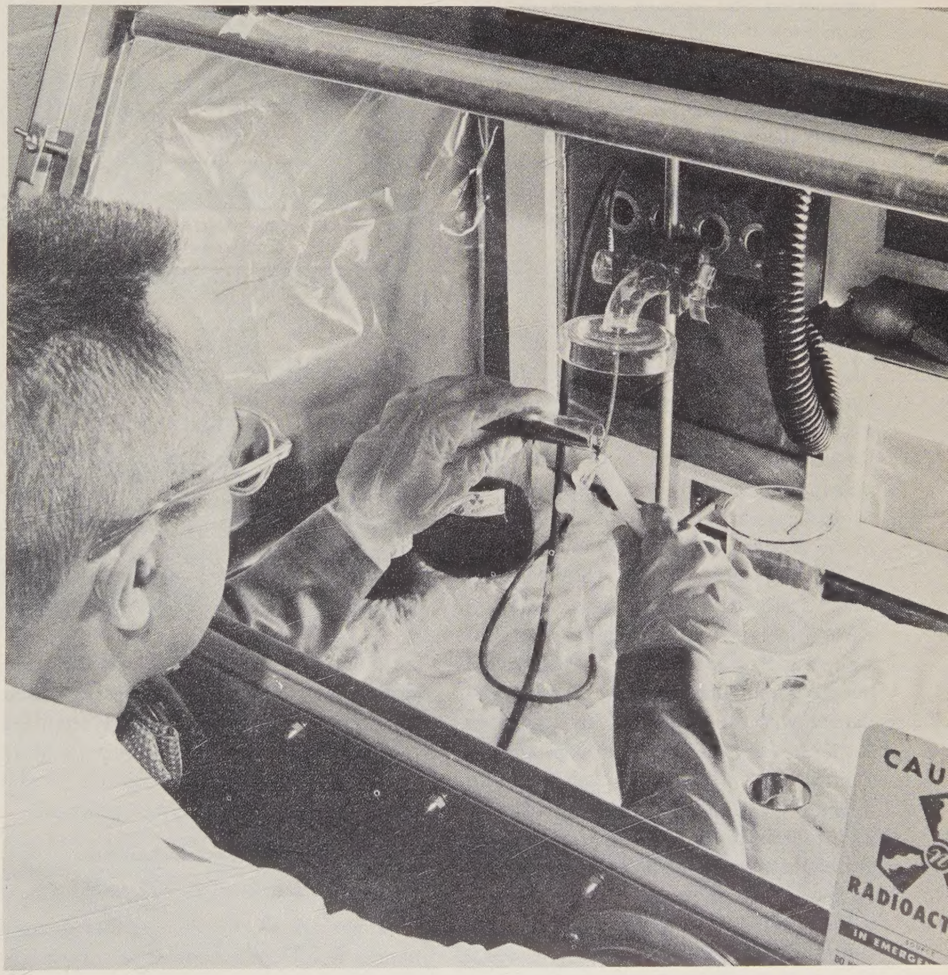
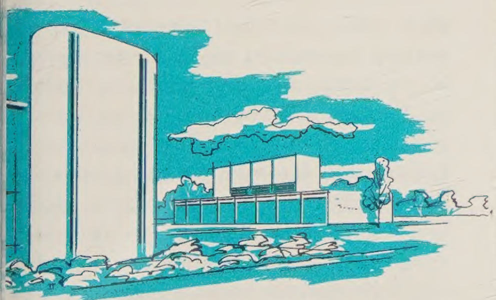
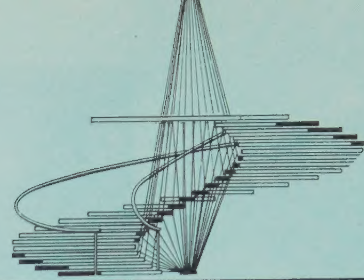


Fig. 2 (right)—One of the special pieces of apparatus used in the Research Staff's Isotope Laboratory is termed a "glove box." Equipped with its own drain and air supply system, the box is specially designed to prevent the spread of radioactive material which might interfere with sensitive measurements made in other parts of the laboratory. While modern buildings and the latest scientific equipment are vital in conducting research investigations today, it is still the people who perform the experiments and make the discoveries. ★



Research Staff Facilities



The engineers and scientists of General Motors Research Staff are pioneers on the frontiers of technical knowledge. Theirs is a task of constant searching, of continual exploring both in fields of science and engineering that have been well trod and in areas of technology where few, if any, have yet dared to venture. While the researcher lives in the present, he works in the future for the future is his business. Most of the investigations undertaken by the Research Staff are long-range—the fruits of which may not ripen for as many as 10 or 20 years. The fruits of scientific investigations are usually facts and data which when applied by design engineers result in products of higher quality, increased durability, and better value to the user. Like similar organizations, the Research Staff is composed of several engineering and applied science departments each of which is responsible for one or more areas of research investigation. While most of the projects carried on in these departments are of a long-range nature, there are often times when their specialized facilities and experience are of great value to the Divisions of General Motors in solving more immediate engineering problems.

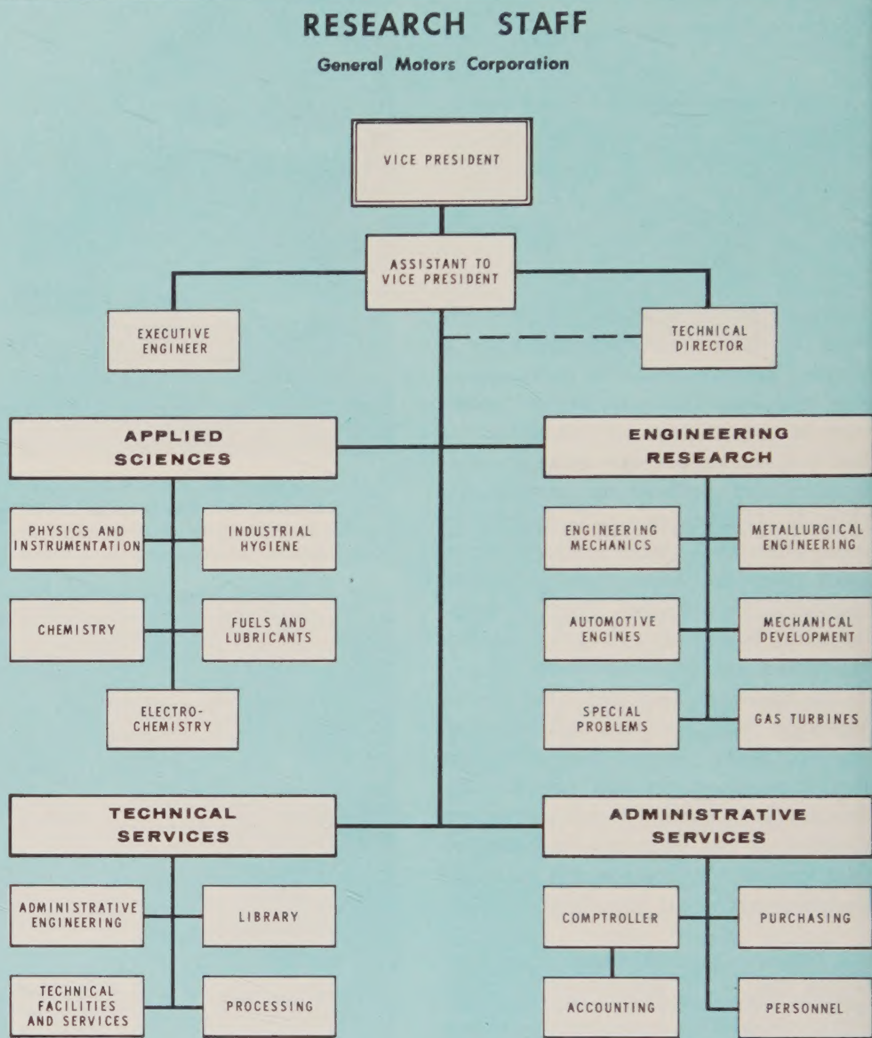


Fig. 1—This organization chart shows the four groups of activities which make up the Research Staff. The 11 Departments grouped under Applied Sciences and Engineering Research are responsible for the Staff's technical projects. The Technical Services group complements and supports the Staff's technical research work, and the Administrative Services group provides the usual accounting, purchasing, and personnel functions necessary to a research activity.

The Research Staff is concerned with the future. In general, its projects are long-range and not aimed at developing a specific new product. Basically, the Research Staff's task is to seek new information which will help General Motors maintain its position of leadership in the automotive industry.

The Research Staff's projects are divided between two main groups of departments—Applied Science and Engineering Research (Fig. 1). The applied science departments are concerned primarily with fundamental investigations in such fields as engine combustion, electronics, ultrasonics, paints and finishes, electroplating, instrumentation, and radioisotopes. The engineering research departments conduct basic studies in spark-ignition engines, gas turbines, vehicle suspension components, various types of bearings, and the fatigue life of automotive components. While these are only a few of the many areas in which Research Staff engineers and scientists work, they are typical and serve mainly to illustrate the general nature of the investigations continually in progress.

Applied Science Departments

Physics and Instrumentation Department

The work of the Physics and Instrumentation Department covers both applied and theoretical physics. Active projects are carried on in spectroscopy, X-ray, ultrasonics, and similar subjects. An infrared spectrograph, designed and built by the Physics and Instrumentation Department, has been used in studies of engine exhaust, paint deterioration, and fuel composition. This group also develops new instrumentation and recording techniques for projects carried on by other departments.

By ALFRED L. BOEGEHOLD, JOHN M. CAMPBELL, and RALPH A. RICHARDSON
General Motors
Research Staff

**The researcher—
exploring the future
is his business**

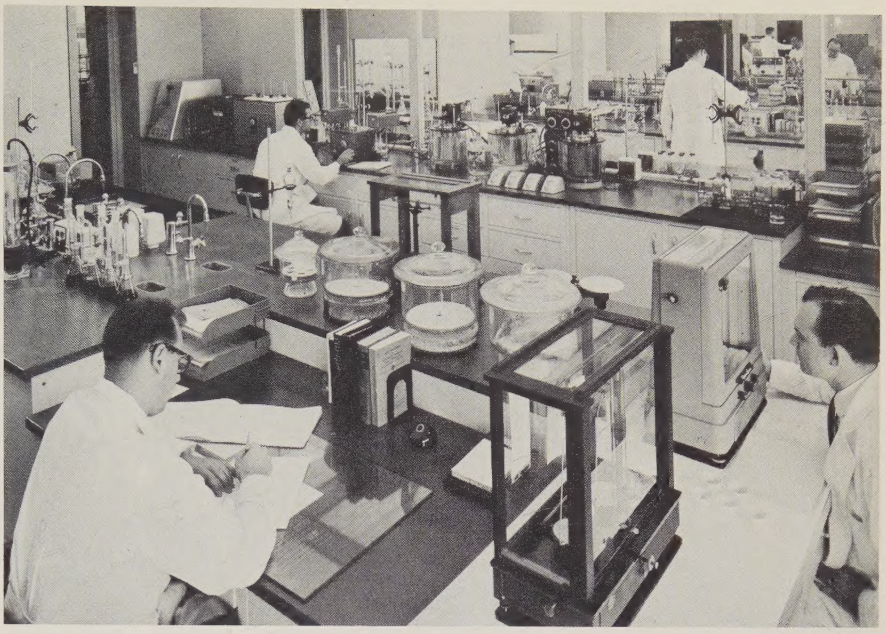


Fig. 2—The Research Staff's Chemistry Department supplements chemistry departments in GM Divisions by providing specialized facilities and analytical services and by developing improved analytical procedures.

Over the past several years important contributions have been made in the application of the electron microscope in metallurgical research. More recently a new radioisotope laboratory building was completed to perform work in this important new field.

Chemistry Department

The fuels, lubricants, plating solutions, metal cleaners, polishing compounds—in fact, most any chemical materials used by the automobile industry—are evaluated by the Chemistry Department (Fig. 2). A large amount of work is devoted to improving the durability of automobile finishes and protective lacquers.

To study the problem of the effects of sunshine, high humidity, and salt air on painted or plated parts the Chemistry Department operates a test field at Coral Gables, Florida. In addition, considerable emphasis is placed on developing new qualitative and quantitative analytical procedures.

Industrial Hygiene Department

The Industrial Hygiene Department is a combination of medical, biological, and engineering groups whose concern is to protect employes from possible sources of occupational health hazards. Major services performed include consultation on problems of ventilation, atmospheric pollution, safe handling of chemicals, and periodic blood analyses of employes.

At the request of a GM manufacturing unit the Industrial Hygiene Department will make studies of new installations of methods or materials to determine if employe exposure might result in occupational illness. With special instruments these researchers can detect minute quantities of gases, dusts, fumes, and mists. Once the conditions are known, controls are devised and safety codes set up to prevent any potential health hazard.

Fuels and Lubricants Department

The principal assignment of the Fuels and Lubricants Department is to discover more about petroleum-base fuels and lubricants. This group has been studying engine fuels for over 30 years. Of primary concern is the combustion of fuel as it occurs in the piston-type internal combustion engine and the relationships between the nature of combustion and the environment within the engine.

Another important area of study is the relationship between the molecular structure of fuels and engine knock. Moreover, studies of pre-ignition, auto-ignition, and other forms of abnormal combustion are part of a continuing program. In addition to the discovery of tetraethyl lead as a knock suppressor, this Department has made many contributions to technical knowledge as a result of fundamental studies in combustion and hydrocarbon chemistry.

Electro-Chemistry Department

The Electro-Chemistry Department combines two areas of research: electroplating and rubber and plastics work. Its laboratories are equipped with special apparatus for duplicating production electroplating processes on a laboratory scale. Most of the work is aimed at developing new plating techniques and solving immediate production problems in electroplating processes.

The rubber and plastics group compounds and evaluates new rubber, adhesive, and plastic materials. Here the primary concern is with application research to fill the gap between the producers of these materials and the GM manufacturing units which use them.

Engineering Research Departments

Engineering Mechanics Department

This group of mechanical engineers and mathematicians is concerned for the most part with fatigue studies and stress analyses of materials and automotive components. Their work in gear design has made automotive gear mechanisms more durable than they were some years ago (Fig. 3). Fundamental studies of residual stress in highly stressed parts have been of great value in extending the service life and durability of automotive and aircraft parts. Results of this fundamental work have contributed to improving the process of shot peening and other mechanical treatments which increase the fatigue life of highly stressed parts. For example, back in 1930 a conventional 90 hp engine required an 11-in. rear-axle ring gear. Today a 7-in. ring gear is used with an engine of over 200 hp.

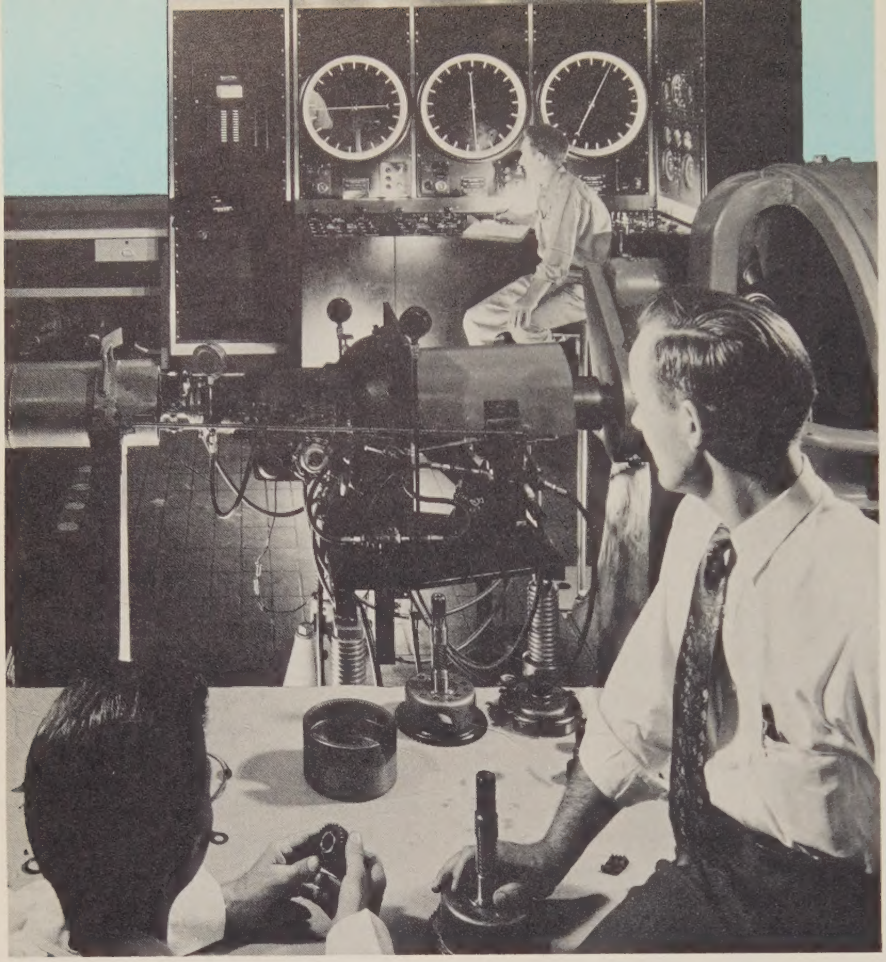


Fig. 3—Fundamental gear studies have long been a part of the Staff's Engineering Mechanics Department and have played an important part in the development of today's high load-carrying gear designs.

Automotive Engines Department

The Automotive Engines Department centers its activites around the development of more efficient piston-type automotive engines, engaging in research on basic engine design and on specific engine components (Fig. 4). Studies of fuel economy, octane requirements, carburetion, and other performance factors are made on dynamometers and by road testing at the GM Proving Ground near Milford, Michigan.

The past work of this Department is largely responsible for present high compression engines in use by GM. The average compression ratio of GM's passenger car engines has increased twice as much during the past 10 years (from 6.5 to 9.0) as in the preceding 20 years. Fundamental studies by the Research Staff have contributed greatly to this progress.

Special Problems Department

The Special Problems Department is a mechanical engineering group. A part of this Department is concerned with the development and production of static and dynamic balancing machines. Balancing machines used for the production balancing of rotating parts are designed, built, and sold by the Research Staff. This work helps to absorb the burden of the extensive machine shop facilities which must be maintained if the various technical departments of the Research Staff are to function effectively.

Another segment of the Special Problems Department is concerned with vibration and noise problems. Included in this work is an active program to develop special vibrating-indicating instruments. This Department also is concerned with mechanical calculators and automatic data processing machines (Fig. 5). It may be that the next generation of engineers will need to know how to use these "mechanical brains" just as today's engineers must know how to operate a slide rule.

Metallurgical Engineering Department

Since metal is one of the basic materials used by General Motors manufacturing units, the Research Staff maintains a large department devoted exclusively to metallurgical research and development (Fig. 6). Briefly, this activity has the task of developing new alloys and new techniques for casting and heat treating both ferrous and nonferrous metals.

Typical of recent accomplishments is a new aluminum dipping process, called Aldip, in which a corrosion-resistant coating of aluminum is applied to steel stampings, forgings, and castings. Work on high temperature alloys for gas turbine components has resulted in the development of GMR-235, an alloy with superior heat resisting properties.

Mechanical Development Department

The Mechanical Development Department is concerned with a variety of projects which include unconventional engines, Diesel engines, free piston engines, fatigue testing, friction, and bearings. The Department's Diesel engine projects are directed at developing higher power output and improving the durability of fuel injectors, pistons, connecting rods, and cylinder liners. A fundamental study of friction is concerned primarily with metals sliding on metals in an attempt to discover why certain metals are compatible with regard to friction and others are not.

During the past five years engineers of the Mechanical Development Department have cooperated with a medical research team in the development of a mechanical pump which serves as a substitute for the human heart during surgical operations for coronary defects.

Gas Turbines Department

The main work of this Department is power plant development, with special emphasis on gas turbines. Its activities include theoretical thermodynamic analyses plus actual design and test work. In addition to their facilities in the Research Administration Building, the Department maintains a separate test building where special facilities are available for investigating gas turbine problems.

During the past several years this group has uncovered much new information about the gas turbine and has developed several automotive-type gas turbine engines for both automotive and transit coach application. The Firebird, first gas turbine powered car in the United States; the Firebird II, a four-

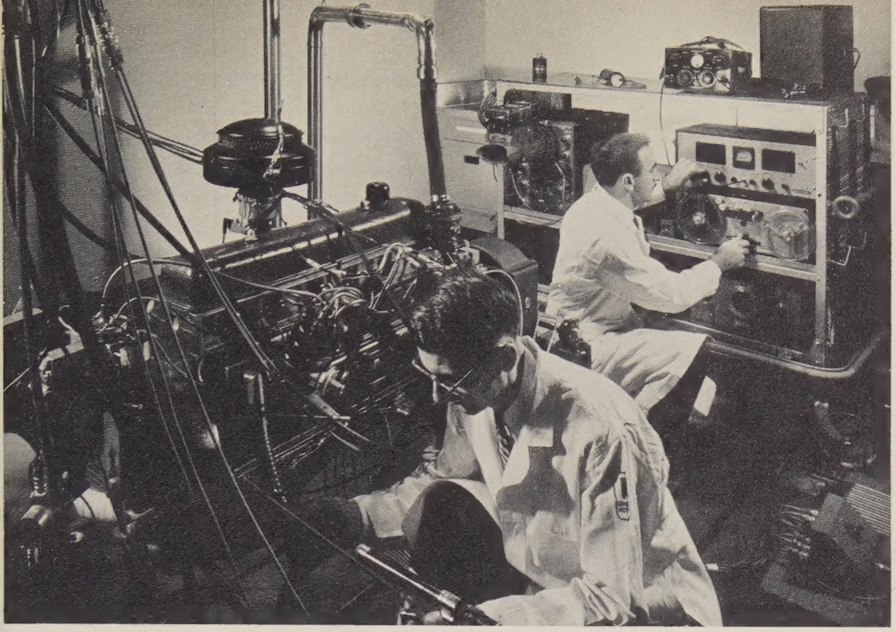


Fig. 4—These research engineers of the Automotive Engines Department are making a noise study of this six-cylinder engine as part of a program evaluating fundamental engine design changes.

passenger gas turbine automobile designed for highway use; and the Turbo-Cruiser, a 36-passenger transit coach, are all powered with Whirlfire gas turbine engines designed and developed by the Research Staff's Gas Turbines Department (Fig. 7).

Technical Services Departments

In order to provide facilities and services to the applied science and engineering research groups a number of technical services are necessary. These include the Administrative Engineering, Technical Facilities and Services, Library, and Processing Departments.

The Administrative Engineering Department provides editorial assistance in the preparation of reports and technical papers and prepares and distributes a variety of technical information to the other departments of the Research Staff and various GM manufacturing Divisions.

The Technical Facilities and Services Department has charge of all maintenance, service, and instrumentation. In addition, this Department designs and supervises the construction of all project facilities and plant re-arrangement programs.

Scientific and engineering textbooks and periodicals are as essential to research work as are instruments and test equipment. The Research Staff Library, one of the finest industrial libraries in the country, consists of more than 35,000 volumes of technical literature. Its periodical subscription list alone totals 347 publications both domestic and foreign. In addition to performing its function in the Research Staff, the Library circulates materials throughout General Motors, in fact, throughout the free world.

The Processing Department is equipped with highly specialized facilities for making experimental parts and apparatus needed by the technical departments in pursuing their various projects. This group contributes importantly to the success of the Research Staff's investigations; the processing group is proud of the fact that it can build anything from a precision timepiece to a complete engine assembly.

Research Staff Buildings

Research Staff facilities at the Technical Center comprise the main Administration Building with its offices and laboratories, four supplementary buildings adjacent, and three special purpose buildings.

The Administration Building

The nerve center of the Research Staff activities is the 690-ft long Administration Building standing at the northern end of the 22-acre Technical Center lake (Fig. 8). It houses the major administrative offices, 250 other offices and laboratories, a 126-seat lecture hall, a 35,000-volume library, and a cafeteria that seats 240 persons.

Its black structural steel framework is based on the 5-ft module, or standardized measurement. The north and south "curtain walls" are of greenish heat- and glare-resistant glass and grey porcelain enamel metal panels which are heat insulating though only two in. thick.

Perhaps the most spectacular architectural feature of this building is the spiral staircase in the main lobby. The steps of polished Norwegian granite, each weighing 1,500 lb, seem to float in space but are actually held by thin stainless steel suspension rods. These rods then

Fig. 5—Electronic computors, operated by engineers of the Special Problems Department, allow the solution of many problems which formerly were considered too complex and time consuming to analyze by conventional methods.

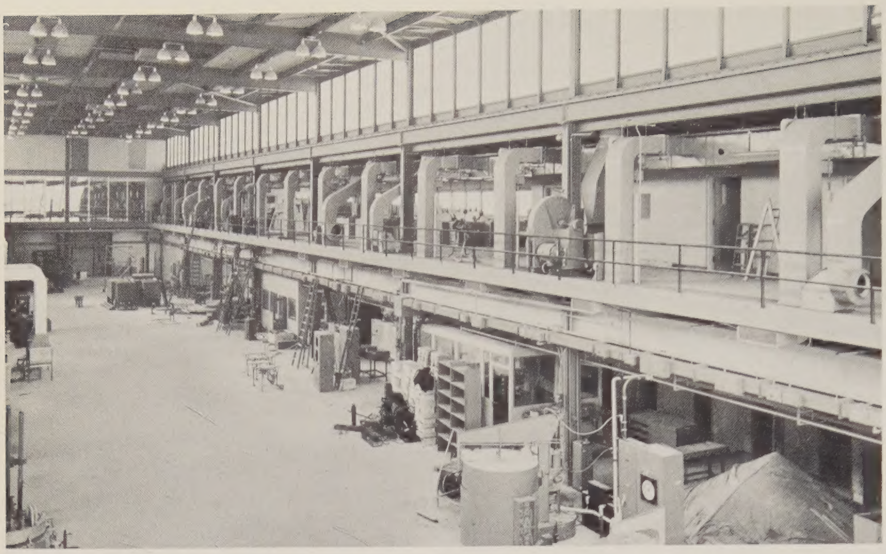


Fig. 6—The foundry of the Metallurgical Engineering Department has a total melting capacity of almost 3,000 lb per hr. High-temperature creep test cells, humidity chambers, and various test facilities are located on the balcony.

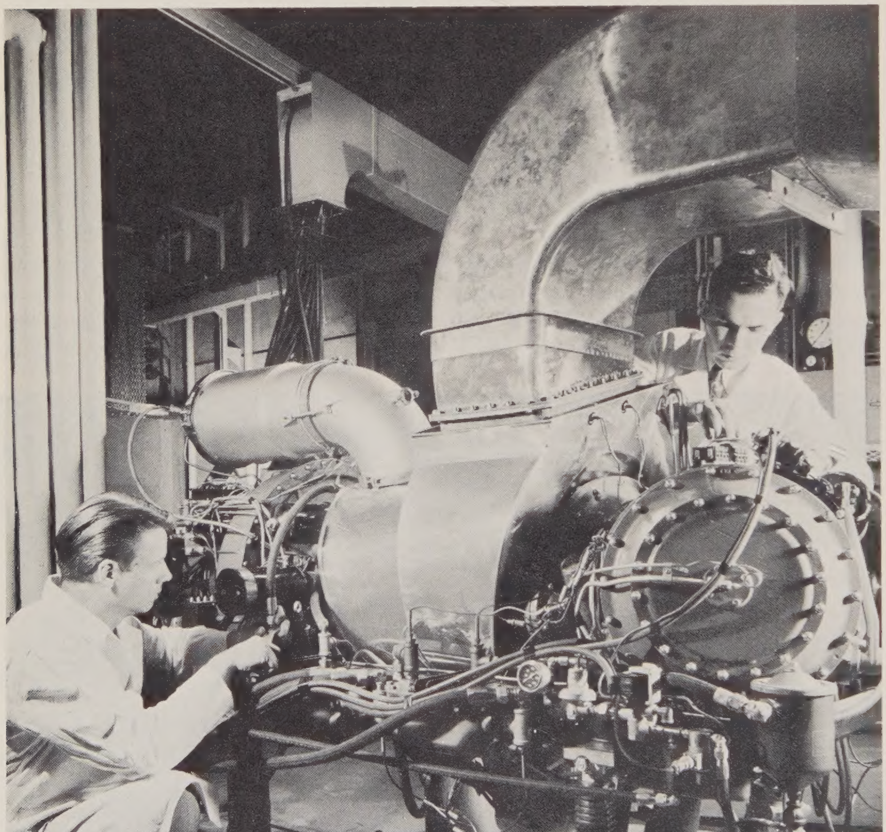


Fig. 7—The development of new concepts in vehicular power plants is one of the functions of the Gas Turbines Department. Shown here is the Whirlfire engine used in the experimental Turbo-Cruiser, the world's first gas turbine powered bus.

spiral up in the center to converge in a cone.

The basic 5-ft module used throughout the building provides for maximum flexibility. The space and function of any laboratory can be changed overnight. The vertical utility columns, spaced at 10-ft intervals along both sides of the fixed frame central corridor, bring hot and cold water, gas, electricity, compressed air, distilled water, vacuum, and even steam to the laboratories and offices. Fumes from the laboratories are exhausted from the building by 72 fans on the roof.

The Research Manufacturing Building

With its power and precision tools this building acts as the tool shop for the research section, manufacturing whatever is needed for various research experiments. A special cold room, where the temperature can go as low as minus 90° F, is big enough to house a transit coach.

The Metallurgical Research Building

The black structural steel framework of the Metallurgical Research Building reveals on the facade its tri-partite divisions. The central section is a high bay housing various kinds of foundry equipment. The two flanking bays are low sections containing subsidiary spaces. Among the many experiments conducted in this building are those involving long-range exploration into alloys and advanced methods of casting.

The Engineering Research Building

The Engineering Research Building houses engine testing dynamometers and other mechanical testing equipment. It is basically U-shaped with a series of 30 test cells on the two sides.

The Fuel Blending Building

The Fuel Blending Building is used for the storage and mixing of various fuels. For safety reasons it is separated from the other buildings. Underground is the tank farm; above the building are cooling towers for process water from the Mechanical Building and the Manufacturing Building.

The Research Wind Tunnel

This tunnel is contained in a rectangular building 184 ft long and 76 ft wide, with concrete walls 12 to 14 in. thick. It was built exclusively for full-size vehicle

tests and is capable of air velocities up to 100 mph. Such items as heating, cooling, ventilation, or air conditioning units can be put through controlled performance tests in the tunnel. Also, engineers can observe effects of changing air temperatures and air-stream speed in tests of body tightness and body noise.

Wind is supplied by two three-bladed variable pitch aircraft propellers 13½ ft in diameter, manufactured by Allison Division's Aeroproducts Operations. The propellers are driven by 400-hp electric motors that have a constant speed of 900 rpm. Temperature can be controlled from a minimum of 60° F to a maximum of approximately 150° F. Rain can be simulated from overhead spray nozzles, and it is possible to produce a deluge up to 100 gallons a minute, the equivalent of 18 in. an hour.

The wind tunnel tapers down at one end into a test section 35 ft long where a 200-hp chassis dynamometer is provided for measuring a test car's power output.

Projecting from the east side of the building is a control room where an operator can control the engine of a test car while observing the test through a large window. In addition to speed and torque, control room instruments measure air velocity, pressure, temperature, and humidity, as well as pressures and temperatures at various points of a test vehicle and its components.

This facility is available to engineers throughout General Motors for studying effects of air velocity and temperature on the operation of automobiles, medium size trucks, and automotive components.

The Turbine Test Building

This building contains seven test cells, two of them large enough for testing present day aircraft jet engines, and a completely equipped shop area. From the outside it has the appearance of a small industrial plant, except for seven large, vertical exhaust stacks and silencers ranged along its east side. Outside the building are a pump house and six fuel tanks.

From an engineering standpoint the outstanding feature of the Turbine Test Building is its maximum flexibility, plus its elaborate and versatile instrumentation. It is equipped for testing virtually all types of gas turbines, ranging from small automotive designs to large aircraft models.

In any test cell the ventilation system can completely change the air in two minutes to prevent any build-up of explosive vapor mixtures. The building has no basement or underground trenches where gas or fuel vapors could accumulate. Exhaust gases, which may reach temperatures over 1,000° F, are water cooled before being emitted from a stack outside the building.

Fig. 8—The Research Administration Building is one of eight Research Staff buildings at the Technical Center. This 690-ft long building stands at the northern end of a 22-acre lake with the other Research buildings grouped behind it. The structural steel framework is based on a 5-ft module. Heat- and glare-resistant glass and grey porcelain enamel metal panels form the north and south walls. The end walls are of red glazed brick.

The Isotope Research Laboratory

The Isotope Research Laboratory is one of the largest and best equipped, privately owned facilities of its kind in the country. This newly completed building has been especially designed to allow the Research Staff to investigate many new uses of radioisotopes as tools in manufacturing, engineering, and research. and to perform basic research and developmental work in the nuclear power field.

The fundamental principles of designing radioisotope facilities—confine, contain, and concentrate—have been rigidly adhered to so as to protect the public domain, to protect employes and the facility, to permit simultaneous operations at both low and high levels, and to conform to existing Federal and State regulations and laws. All loose radioactive material is manipulated in hoods or glove boxes similar to those employed at the University of California and the Reactor Testing Station at Arco, Idaho. These boxes, which are sometimes equipped with heavy lead shielding instead of rubber gloves, completely protect the building and the operator from the material. They are essentially miniature laboratories each with its own isolated, filtered air supply and exhaust, and individual carboy drainage system. The boxes and hoods are housed in isolated laboratory rooms which are continuously ventilated by a thoroughly filtered, automatic, fail-safe, dual-air exhaust system equipped with a gasoline driven emergency power generator. This is part of the elaborate, one-pass ventilating system which provides 10 air changes per hour throughout the Laboratory. All laboratory floors have a load capacity of 300 lb per sq ft so as to accommodate heavy radiation shielding and support the primary shielding which is built into the walls between adjacent rooms. All drain water from the facility is held in special, locked isolation tanks where it is checked for contamination before being pumped out so as to eliminate any possibility that contaminated water might inadvertently be discharged into the Technical Center's own sanitary drainage system.

Conclusion

Most of today's new products—artificial silk, high octane gasoline, synthetic rubber, and light-weight alloys—come from industrial research laboratories backed by enlightened business management. Industrial research produces more new knowledge every year than this generation's grandfathers acquired in a lifetime. In addition to the nation's natural resources of farm, mine, and forest, industrial research constitutes a new form of national resource. Organized research supported by industry has already given much—and offers more for the future.

A Discussion of the Phase Composition of Ball Bearing Steel and Its Measurement

By DONALD P. KOISTINEN
General Motors
Research Staff

Research studies provide new empirical formula for calculating retained austenite

Many research investigations involve the gathering of fundamental information about a particular field of science or engineering. Such information is usually of greatest value in explaining more precisely some obscure or little understood phenomenon. Such was the case in connection with the General Motors Research Staff's investigations into the phase composition of hardened ball bearing steel. Usual practice in determining the percentage of retained austenite in hardened steel was to apply an empirical relationship obtained from data gathered by using the lineal analysis of photomicrographs technique. Studies showed, however, that a more accurate evaluation of retained austenite can be made if a new empirical equation derived from quantitative X-ray diffraction data is used. The effects of variation in phase composition with heat treating conditions on the hardness of ball bearing steel are discussed and compared to results obtained on plain carbon steel.

HARDENED steel is generally a mixture of three crystalline phases—martensite, austenite, and whatever part of the original cementite that did not go into solution in the austenite during the hardening process. These phases are readily recognizable in an electron micrograph of hardened steel (Fig. 1).

The relative proportions of these three crystalline phases may markedly influence the hardness and other physical properties of hardened steel. Hence, it is important to have means of measuring the relative amounts of these phases. Since martensite and austenite are two different crystalline forms of the same chemical composition, no simple chemical means exist for measuring the amount of each present. Certain physical methods, however, do exist for measuring the phase composition of hardened steel. For example, quantitative results can be obtained by analysis of the relative areas of the three phases in micrographs from reflected-light or electron microscopes. However, even the simplest technique for measuring relative areas (lineal analysis) is a long and tedious process, and if only reflected-light micrographs are used, lineal analysis fails to detect some of the smaller grains.

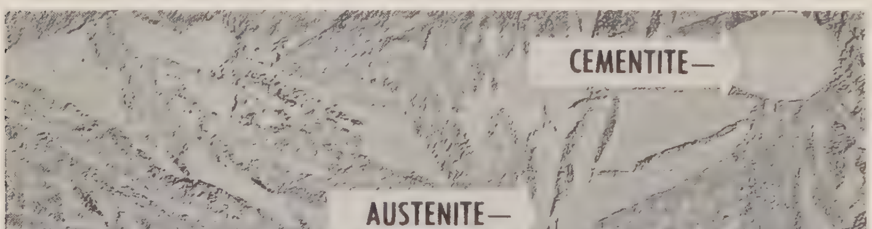


Fig. 1—The three crystalline components of hardened steel are easily distinguished in this electron micrograph (X10,000). Martensite appears as long, needle-like, rough-textured grains; austenite appears as smooth-textured, triangular patches; and cementite is seen as round, smooth-textured areas. This specimen was austenitized at 1,600° F and quenched in six to eight per cent NaOH solution at room temperature.

X-ray diffraction analysis, on the other hand, is particularly well adapted to phase composition studies since it detects differences in crystal structure. Futhermore, it offers the possibility of much quicker analyses even on materials with small grain size.

A quantitative X-ray diffraction technique for the measurement of the phase composition of hardened steel, first proposed in 1948, has been modified by the GM Research Staff[1,2]. The modified technique makes use of monochromatic X-radiation and possesses a degree of sensitivity such that the limit of detectability is less than one-half per cent of the minor phase. It has been found that the relative percentages of the phases in steel can be measured with a reproducibility of less than plus or minus one per cent and an accuracy within one per cent of the absolute value.

This paper will illustrate the type of information which can be obtained with this quantitative X-ray diffraction technique by describing the results of a study of the effects of heat treating conditions on the phase composition of ball bearing steel (SAE 52100). SAE 52100 is an important commercial grade steel which is chosen for ball bearings and similar applications because of the reproducibility of its physical properties in the hardened state (Table I). It has been found that this steel has a reproducible phase composition almost within the reproducibility of the X-ray diffraction technique.

Samples and Treatment

The samples of SAE 52100 steel used in the X-ray diffraction determinations

were obtained from several suppliers in this country and from Sweden. All samples for these studies were either flat pieces less than 3/16 in. thick or bearing balls less than 1/2 in. in diameter so that they were completely through-hardened. The effects of curvature on X-ray diffraction determinations were found to be negligible[3]. Most samples were copper plated during heat treatment or were heat treated in an argon atmosphere furnace so that there was no reaction between the steel and the heat treating atmosphere. Samples which were prepared by other investigators were studied to ascertain that no extraneous variables were affecting the phase composition[4]. All samples were held at the austenitizing temperature for a time sufficient to establish equilibrium conditions, were quenched, and then tempered at 250° F to 300° F for one-half hour.

Experimental Results

The effects of varying austenitizing temperature and quenching media on the phase composition of hardened ball bearing steel (SAE 52100) were determined using the quantitative X-ray diffraction technique (Fig. 2, Curves I and II). Other investigators have made similar studies using the older technique of lineal analysis of light micrographs (Fig. 2, Curve IV)[5]. The two averaged points, using the lineal analysis technique, at the high austenite level are in excellent agreement with the X-ray diffraction analyses. The averaged point at seven per cent austenite, however, falls well below the curve of the X-ray diffraction results. Considering the extremely fine grain size of this steel, it can be concluded that the lineal analysis technique must have failed to detect a large share of the retained austenite grains in the most completely transformed specimens having low austenite.

According to the results of the X-ray diffraction technique, the percentage of austenite retained (Fig. 2, Curves I and II) increases continuously with increasing austenitizing temperature, while the percentage of cementite (Fig. 2, Curve III) decreases exponentially until, at about 1,800° F, all of the carbon from the cementite has been dissolved. Quenching in oil (Fig. 2, Curve I) which is a slower quenching medium than the six to eight per cent NaOH solution (Fig. 2, Curve II), retains slightly more austenite even though the amount of carbon in solution is the same. Most SAE 52100 steel parts are oil quenched to minimize distortion and residual stresses.

Since these curves were established, the phase compositions of several dozen oil quenched specimens from various sources have been determined, and all have fallen very close to, or within, the standard deviation band. On one occasion, when the retained austenite content of a specimen was found to be two per cent higher than expected, a closer check of the furnace disclosed that the controller kept the furnace 25° F too high. This suggests the possibility of using the X-ray diffraction technique for quality control applications.

Extrapolation of the X-ray diffraction data to zero per cent austenite (Fig. 2, Curves I and II) intercepts the temperature coordinate at approximately 1,340° F. It is very significant that this is the accepted Ae_1 temperature for SAE 52100 steel[6]. The Ae_1 temperature is the lowest temperature at which austenite is stable. The 1,340° F intercept appears more logical than the 1,400° F intercept obtained by lineal analysis of light micrographs (Fig. 2, Curve IV). The discrepancy in the latter probably results from inability of the method to see all the fine grained austenite.

X-ray diffraction results also have been obtained on a plain carbon steel (SAE 1095) whose composition is given (Table I). The per cent of retained austenite (Fig. 3, Curves I and II) in hardened SAE 1095 steel increases with increasing austenitizing temperature as long as the per cent of cementite (Fe_3C) decreases (Fig. 3, Curve III). All of the carbon is in solution by 1,700° F, however, and at higher austenitizing temperatures no further increase in the per cent of austenite retained is observed. This saturation value of the per cent of retained austenite has been found to vary from lot to lot of SAE 1095 steel from as high as 18 per cent (Fig. 3, Curve I) to as low as 12 per cent (Fig. 3, Curve II). This saturation in plain carbon steel was also observed by those who applied the lineal analysis technique and presumably led them to assume that a similar saturation occurs in the retained austenite content of SAE 52100 steel (Fig. 2, Curve IV). To show that no such saturation value exists in SAE 52100 steel, samples have been flame austenitized at temperatures in excess of 2,000° F and have been found to contain as much as 55 per cent retained austenite.

Effect on Hardness

The effect of the phase composition on the hardness of SAE 52100 and SAE 1095 steel has been studied (Figs. 2 and 3, shaded bands). The hardness of the ball bearing steel (SAE 52100) increases with increasing austenitizing temperature in the range of rapidly decreasing cementite content (and, hence, in the range of increasing carbon in solution). After approximately 85 per cent of the cementite has been dissolved (at approximately 1,550° F) the increase in carbon content is not sufficient to overcome the effect of the increasing percentages of retained austenite. Since the retained austenite is relatively soft and ductile, the effect of increasing percentages is to decrease the overall hardness of the steel. Thus, the phase composition study has led to an explanation of the maximum in the hardness of SAE 52100 steel after austenitizing at 1,500° F to 1,600° F.

The hardness of the SAE 1095 steel (Fig. 3) increases with increasing austenitizing temperature in the range of decreasing cementite concentration (that is, with increasing carbon in solution). At temperatures of 1,700° F and above, after all of the cementite has dissolved, the hardness remains at some maximum value since the retained austenite content in this steel does not change.

Calculation of M_s Temperature

The primary factor governing the amount of austenite which transforms to martensite (and, thus, also the amount of austenite which is retained) is the difference between the temperature at which the transformation starts and the ultimate temperature to which the specimen is quenched. The temperature at which the transformation to martensite

Table I—Chemical Composition of SAE 52100 and SAE 1095 Steels

SAE No.	C	Mn	P max.	S max.	Si	Ni	Cr
52100	0.95—1.10	0.25—0.45	0.025	0.025	0.20—0.35	—	1.30—1.60
1095	0.90—1.05	0.30—0.50	0.040	0.050	0.15—0.30	—	—

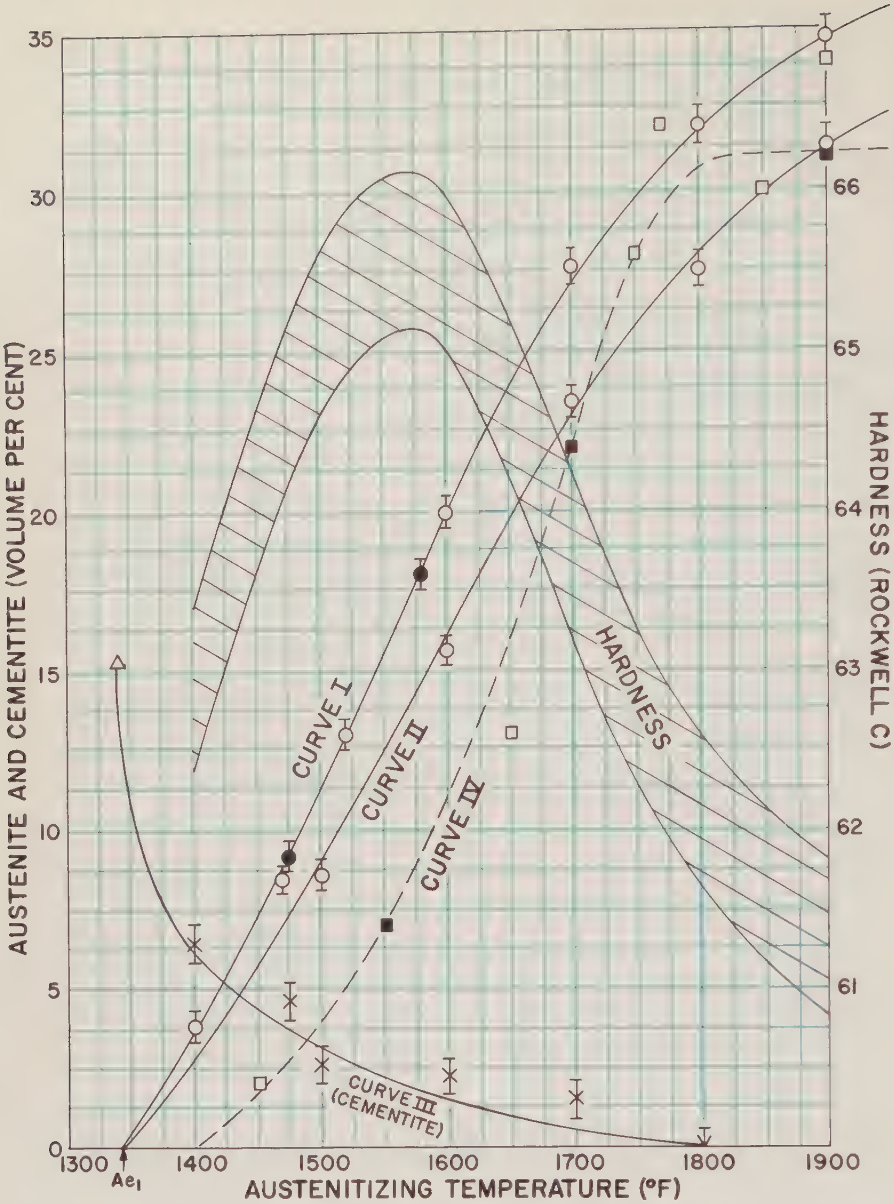


Fig. 2—The phase composition and hardness of SAE 52100 ball bearing steel is a function of austenitizing temperature. Curve I shows the per cent austenite after oil quenching as determined by X-ray diffraction analyses. Curve II shows the per cent austenite after quenching in six to eight per cent NaOH solution as determined by X-ray diffraction analyses. Curve III indicates the per cent cementite as determined by X-ray diffraction analyses. (The per cent of cementite at 1,340° F is calculated on the basis that all of the carbon is combined as cementite and on the relative densities of ferrite and cementite.) Curve IV shows the per cent austenite after quenching in nine per cent brine as determined by other investigators using microscopic lineal analyses[5]. The vertical bars drawn through most of the plotted points indicate standard deviation of X-ray diffraction determinations. Solid points are averages of several determinations. The hardness curve is drawn as a shaded band to indicate spread of hardness measurements.

starts is designated the M_s temperature and T is used to designate the ultimate quenching temperature. Thus, the increase in the retained austenite content of SAE 52100 at room temperature with higher austenitizing temperatures reflects a lowering of the M_s temperature. It has been shown that lineal analysis data revealing the extent of transformation to martensite for temperatures below the M_s for low alloy steels all fit a single empirical equation[6]:

$$\textit{Per cent Retained Austenite} = 3.05 \times 10^{-14} [820 - (M_s - T)]^{5.32}.$$

This equation relates the per cent of austenite retained at the ultimate quenching temperature T in degrees F to the difference between the M_s temperature and T (usually room temperature). From this equation it is possible to calculate the M_s temperature for SAE 52100 after austenitizing at any given temperature from the observed amount of retained austenite at room temperature.

A comparison can be made between experimentally determined M_s temperatures for SAE 52100 steel and M_s temperatures calculated from the X-ray diffraction data (Fig. 4). The experimental curves (dashed lines) were determined by the other investigators using two microscopic techniques[5]. The upper dashed curve (Fig. 4, Curve I) is drawn through points where the first traces of martensite in the austenite were detected. The lower dashed curve (Fig. 4, Curve II) is drawn through points determined by extrapolation to zero per cent martensite of lineal analysis determinations of the amount of austenite transformed to martensite at temperatures just below the M_s. The lower solid curve (Fig. 4, Curve III) shows the M_s temperatures calculated from the X-ray diffraction data on SAE 52100 steel quenched in six to eight per cent NaOH solution. The agreement between the experimental and calculated M_s temperatures is fair at low M_s temperatures (corresponding to high austenite values where the lineal analysis and X-ray diffraction determinations agree), but there is an increasing discrepancy at higher M_s temperatures (where the retained austenite content is low). This is probably due to the fact that the equation normally used for calculating per cent retained austenite is based on microscopic lineal analysis data which gives too low austenite values at low concentrations. A new equation-based X-ray diffraction determination makes the M_s temperatures calculated from the retained austenite content (Fig. 4, Curve IV) agree almost exactly with the M_s temperatures based on the first traces of martensite detected (Fig. 4, Curve I). This equation is:

$$\textit{Log (Per cent Retained Austenite)} = -2.80 \times 10^{-3} (M_s - T) + 2$$

where T is the ultimate quenching temperature in degrees F (generally room temperature). This equation has the virtue of being somewhat easier to evaluate quantitatively than the equation developed from lineal analysis data. This new equation is also of the same general form as those describing many other decay systems in physics, such as radioactive decay. Preliminary investigations have shown that this equation also applies to some other low alloy steels.

Summary

The crystalline phase composition of steels used for ball bearings can be

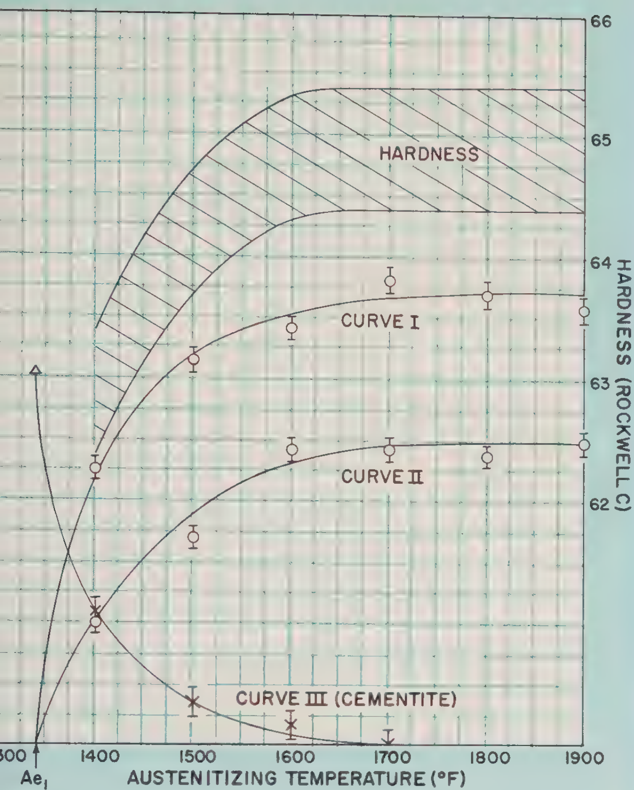


Fig. 3—The phase composition and hardness of SAE 1095 steel is a function of austenitizing temperature. Curve I shows the per cent austenite in Lot 1 after quenching in six to eight per cent NaOH solution as determined by X-ray diffraction analyses. Curve II indicates the per cent austenite in Lot 2 after quenching in six to eight per cent NaOH solution as determined by X-ray diffraction analyses. Curve III shows the per cent cementite as determined by X-ray diffraction analyses. (The per cent of cementite at 1,340° F is calculated on the basis that all of the carbon is combined as cementite and on the relative densities of ferrite and cementite.) The vertical bars through the plot points indicate standard deviation of the X-ray diffraction determinations. The hardness curve is drawn as a shaded band to indicate spread of hardness measurements.

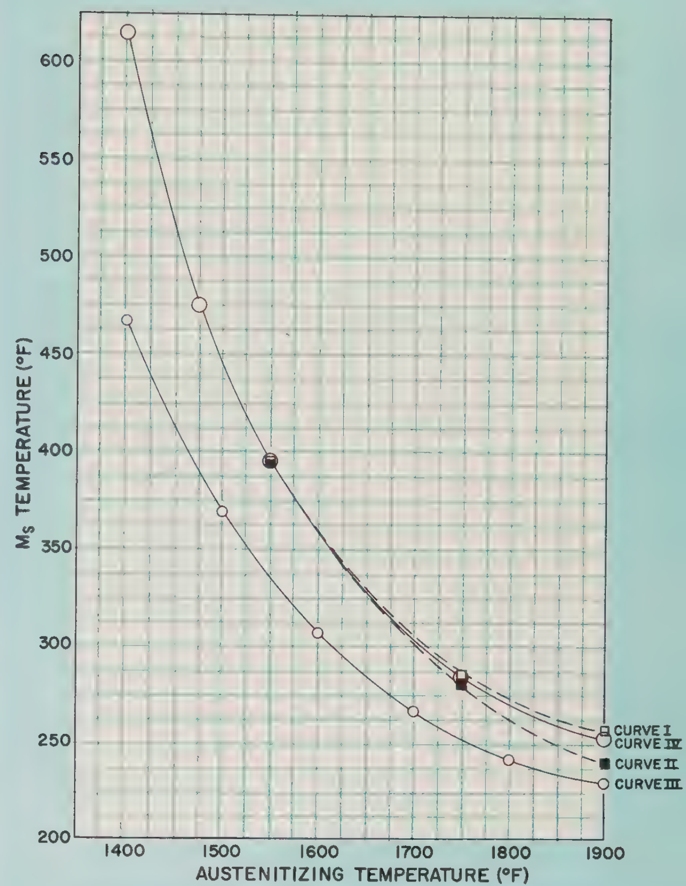


Fig. 4—These curves show the effect of austenitizing temperature on the M_s temperature of SAE 52100 steel. Curve I is based on the first traces of martensite detected microscopically. Curve II is based on extrapolation of martensite transformation curves to zero per cent martensite. Both Curves I and II were taken from the literature[5]. Curve III shows M_s temperatures calculated from the X-ray diffraction data on the austenite content using an empirical equation developed from data gathered by the lineal analysis of photomicrographs. Curve IV shows M_s temperatures calculated from the X-ray diffraction data on the austenite content by the new equation: *Log (Per cent Retained Austenite)* $= -2.80 \times 10^{-3} (M_S - T) + 2$, where T is the quenching temperature (degrees F).

determined more accurately using a quantitative X-ray diffraction technique than by using the method of lineal analysis of photomicrographs. This is particularly true with regard to retained austenite.

An empirical equation for determining the percentage of retained austenite in SAE 52100 steel is simpler and more accurate if developed from X-ray diffraction data than from data obtained by lineal analysis techniques.

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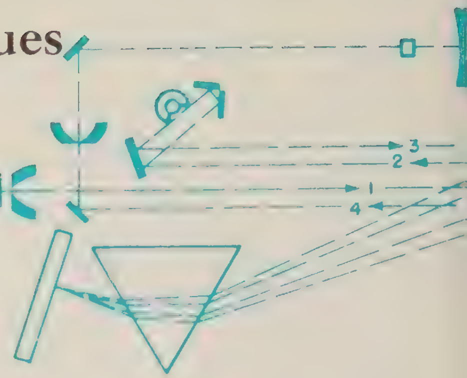
The Application of Radiation Techniques to Engine Combustion Studies



In the internal combustion engine it is desirable to develop the maximum temperature possible by liberating heat from the fuel and air at the proper time in the engine cylinder. At the same time, it is equally desirable to minimize heat transfer from the combustion products to the engine parts. In order to develop the maximum temperature possible it is necessary to control the rate of the combustion reaction, and this can only be done by "guess" unless the mechanism of the reaction is known. Temperature is important not only because it is a measure of combustion performance, but also because it is a controlling factor in the flow of heat to the engine parts. For the past 35 years the General Motors Research Staff has been active in studying engine combustion phenomena. In conducting these studies a wide variety of research techniques has been applied. Rapid-recording pressure indicators, high-speed motion pictures, gas sampling devices, mass spectrometers, and a number of different optical spectra and total radiation-recording instruments represent a few of the more esoteric techniques. Radiation techniques involving both spectra and total light emission studies are discussed in this paper.

For nearly all of its history the spark-ignition internal-combustion engine has been bothered by one nagging combustion problem—*knock*. Knock is the name given to a sudden inflammation of the last part of the charge to burn in an engine combustion chamber before the charge is entirely consumed by the normal flame front. In normal, well-behaved combustion the spark ignites the fuel-air mixture in the chamber shortly before the piston reaches top-dead-center, and a flame front moves from the spark outward across all of the combustion chamber in an orderly manner. GM Research engineers first showed this flame movement with high-speed motion pictures in 1936[1]. In knocking combustion flame movement is similar to that of non-knocking combustion until the time at which the last part of the charge to burn (the so-called "end-gas") suddenly becomes completely inflamed in a period of time which may be shorter than 0.0004 sec. The sudden inflammation of the end-gas sets up pressure waves in the combustion chamber gases which travel back and forth across the chamber and excite the cylinder walls to forced vibrations, producing the characteristic knocking sound. These waves also accelerate heat transfer to the engine parts.

Of course, even the crude description of knock just given was unavailable in the early days of engine development. The first clues to the nature of knock were the records of pressure indicators installed in engine combustion chambers. These showed pressure oscillations beginning late in the knocking combustion process, oscillations, which were of the same frequency as the audible sound, and which could be related to traveling wave fronts visible in photographic flame records[2]. High-speed motion pictures provided the final, clinching evidence as to the physical nature of engine knock.

By employing stroboscobic techniques, a team of GM Research Staff scientists managed to record spectra of the visible light emitted by the flame front and the burned product gases in an operating engine[3,4]. It was demonstrated that most of the heat release occurred in the

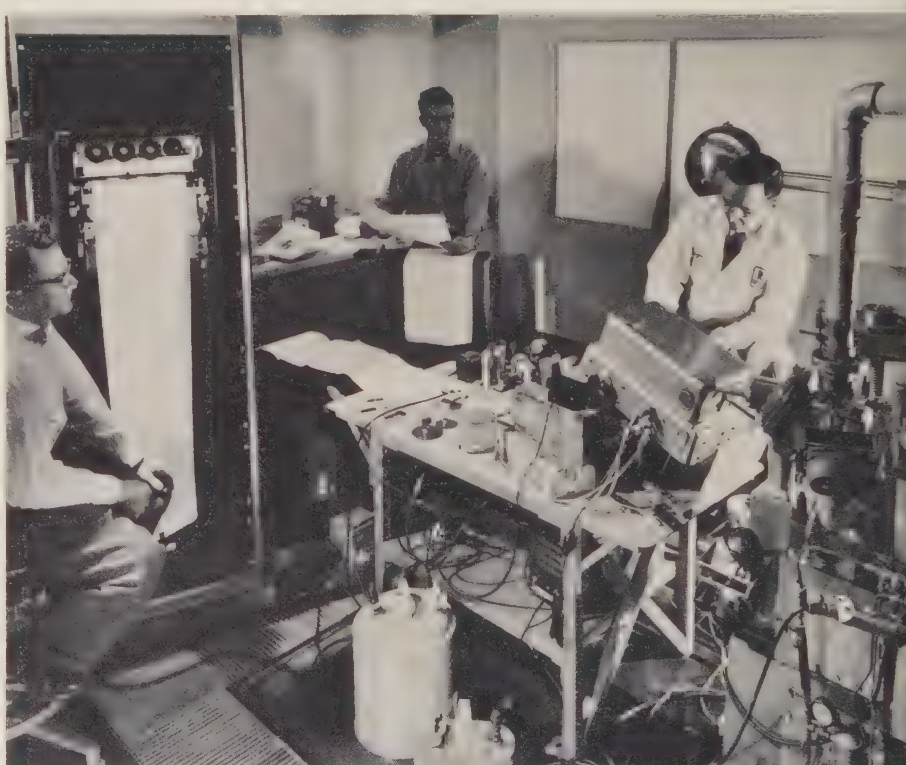


Fig. 1—Radiation from the cylinder gases of the single-cylinder research engine passes through a ⅜-in. diameter window in the combustion chamber wall and is directed into the entrance slit of the spectrometer by a silver reflection tube. The spectrum appears on the recorder shown at the left.

By WILLIAM G. AGNEW
General Motors
Research Staff

Spectra and total light emission studies provide new clues to engine combustion phenomena

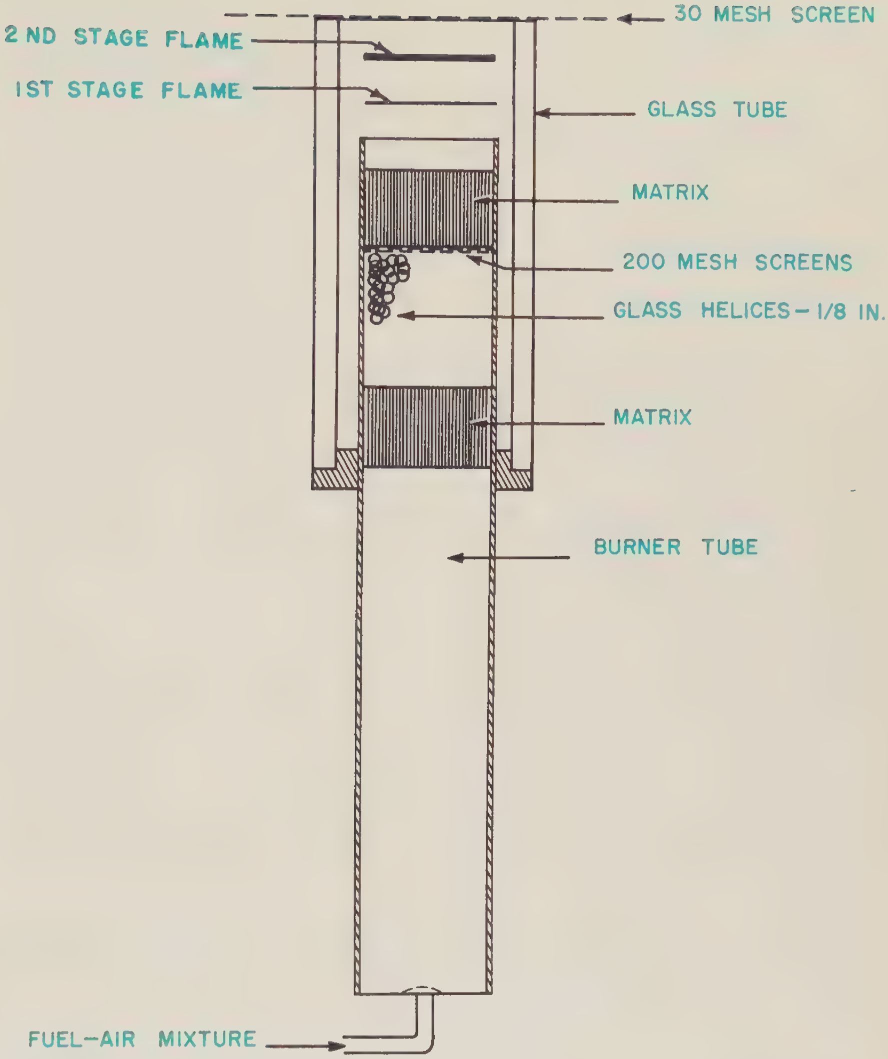


Fig. 2—Laboratory burner spectra illustrated in Fig. 4 have been recorded using a so-called "flat-flame burner." With this burner it is possible to maintain horizontal, flat, two-stage cool flames stabilized in space indefinitely. Spectra can be recorded for any horizontal slice of the reacting gases.

relatively narrow front dividing the burned and unburned gases where the spectrum closely resembled that of the inner cone of a Bunsen flame. C_2, CH, and OH radicals were the primary light emitters from this front. The spectrum of the light from the product gases closely resembled that of the Bunsen outer envelope, where the emission apparently results primarily from excited CO_2 molecules.

The GM researchers also measured gas temperatures in the engine combustion chamber, using the sodium-line reversal technique[5]. This is a popular spectroscopic technique involving the addition of traces of sodium to the engine intake mixture and recording with a spectroscope the relative emission and absorption of light by the sodium at a wavelength of 5,895 Angstrom units (one Angstrom unit is 10^{-10} meters). These measurements demonstrated experimentally for the first time that temperature gradients as high as 800° F exist in the engine combustion chamber at the time of completion of combustion. They also indicated some of the effects of engine knock on the heat transfer to the engine parts.

Another important investigation in connection with engine combustion phenomena involved a correlation between the pressure developed from combustion in a spark-ignition engine and the flame front travel as recorded in high-speed motion pictures[6,7,8]. This correlation permitted the calculation of the per cent of charge burned as a function of time in the cycle and provided useful information on the rates of heat release and heat loss to the combustion chamber walls.

Attempts to explain the chemical nature of spark-ignition engine knock led to further radiation studies of the end-gas, that is, the unburned portion of the charge just prior to knock. Absorption spectra recorded with a spectrometer attached to an operating engine showed that formaldehyde was produced in the end-gases prior to inflammation and gave the first evidence of the so-called "preflame reactions" in engines[9,10]. Spectra recorded with tetraethyl lead added to the fuel demonstrated the decomposition of this compound and the appearance of atomic lead in the end-gas[11]. Still later studies using extremely sensitive photomultiplier detectors showed that the preflame reactions occurring in the spark-ignition engine end-gas actually emit very weak visible light[12,13]. The relationship between this light emission and the occurrence of knock has been extensively studied, since it now appears clear that the preflame reactions are closely associated with the sudden self-ignition of the end-gas, which is recognized as engine knock.

Some Current Combustion Problems Suitable for Radiation Studies

In spite of the many years of research on spark-ignition engine knock, during which the physical nature of this phenomenon has been fairly well defined, the chemical reactions involved have remained obscure. The chemistry of the preflame reactions occurring in the engine end-gas and the self-ignition reac-

tion itself are understood only in a most general way. It has been discovered, for example, that the engine preflame reactions are similar in many respects to a type of slow, low-temperature reaction long known from studies with laboratory reaction tubes and bombs as "cool flames." The discovery of this relationship has brought to bear on the knock problem an extensive fund of chemical knowledge already developed from laboratory studies and has opened new avenues for continued research.

It has been recognized for a long time that the normal ignition process in Diesel engines is a self-ignition process not very different from the knock phenomenon in spark-ignition engines. In recent years evidence has been acquired indicating that preflame reactions of the same general type as those in spark-ignition engines play an important, if not dominant, role in the practical problems of both starting Diesel engines at low temperatures and Diesel knock. Thus, in general, preflame reaction studies should provide useful information for improving the performance of both of these types of engines.

A current combustion problem of much concern to the automotive engineer is that of *preignition* or ignition of the fuel-air mixture in the spark-ignition engine cylinder by hot particles of combustion chamber deposits prior to the normal spark-controlled flame. Such pre-ignition nullifies all control of the combustion process which has been designed into the engine by spark timing and combustion chamber shape. The mechanism by which the mixture is ignited by these particles is not entirely understood, but it is quite possible that low-temperature "preflame reactions" of one type or another are again involved.

"Smog" is a term which is by now familiar to everyone. In Los Angeles, for example, automotive exhaust gases have been pointed to as a contributor to smog, since it is now known that unburned hydrocarbons and oxides of nitrogen are emitted in the engine exhaust in more than negligible quantities. It is suspected that both of these types of substance are involved in the very complicated atmospheric reaction producing smog. In an engine unburned hydrocarbons result from localized regions of the combustion chamber near the cool walls or where the mixture is excessively diluted by residual gases. In these regions combustion is incomplete, and unburned fuel and intermediate reaction products result. The final solution to this problem depends first of all on detecting the location of these regions of incomplete combustion and understanding the nature of the reactions taking place in them. Radiation techniques are applicable in both instances.

In the fields of gas turbines and jet engines there long has been a need for some means of measuring high gas temperature rapidly and accurately. Thermocouples, the most common devices in use today, are subject to considerable error due to conduction, radiation, velocity, and time response errors when used in high-velocity gas streams such as those issuing from gas turbine combustors. At the very high temperatures reached in the burning zones of the combustors, thermocouples are subject to melting. Here then is a situation where radiation techniques of temperature measurement have a direct application if the practical experimental and instrumental difficulties can be overcome.

From the jet engine field also comes the problem of measuring the radiant heat transfer from flames to the combustor walls. In order to keep jet engines in operation for long periods with a minimum of maintenance the combustor liner, which contains the flame gases at temperatures up to 3,500° F or more, must be kept cool. Heat transfer from the gases to the liner by conduction, convection, and radiation must be kept to a

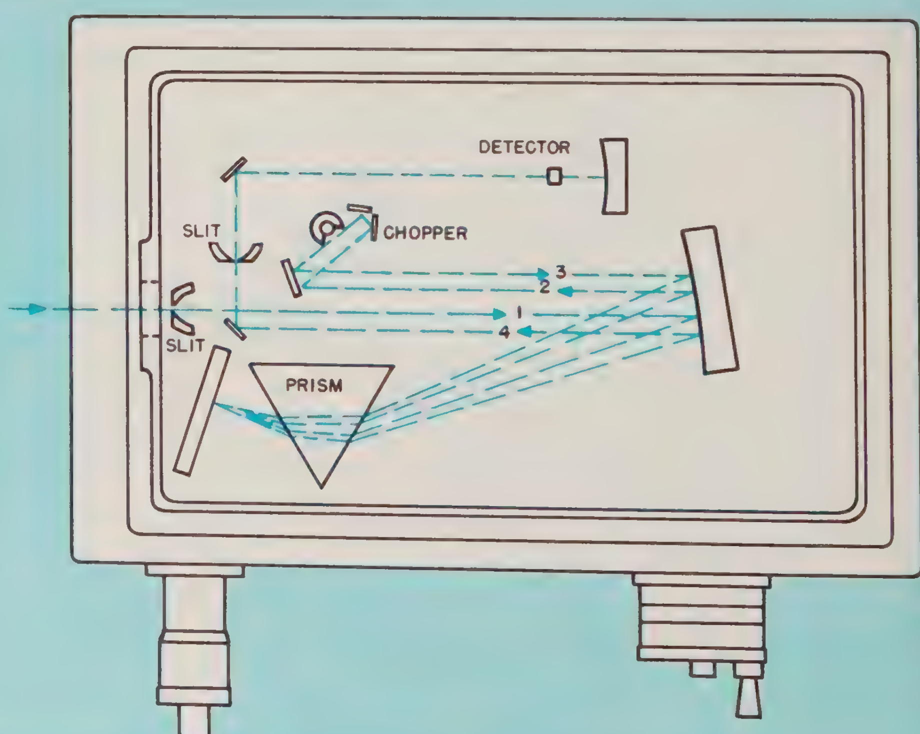


Fig. 3 (right)—A plan view of a modern commercial spectrometer of the type used in the current engine combustion studies is shown in diagrammatic form. The radiation to be studied enters through the narrow entrance slit, is collimated, and passed four times through a prism which disperses the radiation into its many wavelenths. One wavelength of radiation finally passes out through the exit slit and is focused onto a radiation detector. Sensitive thermocouples, lead sulfide photoconductive cells, and photomultiplier tubes all have been used as detectors in recent work. The electrical signal from the detector is amplified and recorded on a moving chart recorder (not shown). As the chart paper moves, the rotation of one mirror in the spectrometer sweeps successive wavelengths across the exit slit and thus plots the spectrum automatically.

minimum. To date studies of the radiant heat transfer have not even reached the point where adequate measurements have been made.

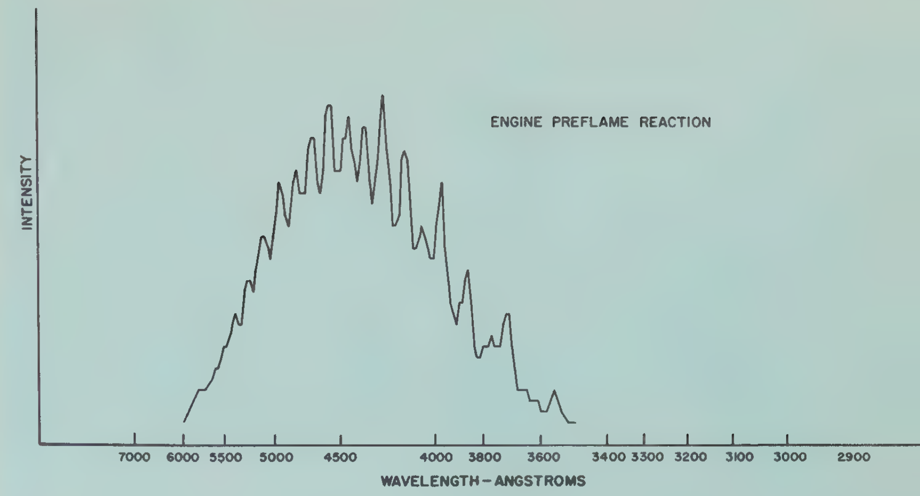
Methods Used to Study Preflame Reactions

Spark-ignition engine preflame reactions have been attacked from two directions. Attempts have been made to study the composition of the reacting gases in an engine cylinder by the recording of infrared emission spectra, and parallel attempts have been made to measure the temperature of the reacting gases in the engine by infrared radiation techniques (Fig. 1). As an aid to both of these projects, corresponding studies have been made with similar "cool flame" reactions stabilized in a laboratory burner (Fig. 2). The temperature measurement work has been extended to include development of a radiation temperature measuring technique applicable to jet engines for Allison Division, and in connection with this work some determinations of radiant heat transfer from jet engine combustor flames also have been made.

Before mentioning a few of the results from these specific studies, it should be useful to discuss briefly the general nature of the spectroscopic technique and the instrument requirements.

A diagram in which the intensity of emitted radiation is plotted as a function of the wavelength of the radiation is termed a *spectrum.* The spectrum of visible light extends from the blue or violet region at about 3,500 Angstroms to the red region near 7,500 Angstroms. The invisible ultraviolet spectrum extends downward from 3,500 Angstroms, while the invisible infrared region begins at 0.75 microns (one micron is 10,000 Angstroms or 10^{-6} meters) and extends to the microwave region near 200 microns.

All substances emit radiation when they are heated, and the spectrum of the emitted radiation is characteristic not only of the particular substance emitting but also of the temperature of the material. Thus, the spectrum of a substance is doubly useful, for it not only permits the identification of unknown chemical species in a gaseous mixture but, with the application of the laws of thermal radiation, it also permits the calculation of the gas temperatures. However, like most other situations in engineering or scientific research, there are many parameters to be considered, both theoretical and experimental.



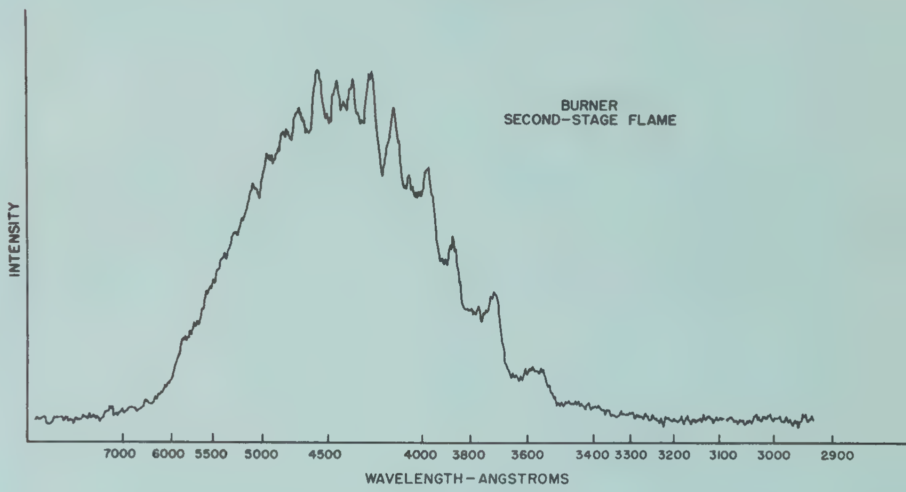


Fig. 4—The visible spectrum of the first-stage burner cool flame has the same formaldehyde band peaks as the second-stage burner and the engine preflame spectra shown above, but the first-stage burner cool flame differs in that it has some additional unidentified radiation at longer wavelengths. It should be pointed out, too, that even the second-stage flame spectrum does not always resemble the engine spectrum. If the second-stage flame is made leaner than that shown, the formaldehyde band peaks are replaced by bands of the HCO radical. HCO bands have not yet been found in the engine preflame spectra, but it is felt that the transition from formaldehyde to HCO in the burner spectra may be fundamentally related to the transition from preflame to normal flame reactions.

On the theoretical side, it must be remembered that materials can be excited to radiation by other than thermal means. In particular, chemical reactions often produce molecules in energy states higher than those predicted by thermal equilibrium. Radiation by these molecules, called *chemiluminescence* may give completely erroneous indications of temperature. On the other hand, such radiation may provide interesting information about the reaction. Another common difficulty often encountered results from the fact that the spectra from a number of similar compounds may appear almost the same in particular wavelength regions. Thus, the identification of particular species is sometimes uncertain.

The basic instrument used for spectroscopic radiation studies is the spectrometer (Fig. 3). Practical experimental complications involved in its use are generally problems having to do with the means for separating the various wavelengths of radiation and detecting and recording very low intensities. However, recent advances in the development of spectroscopic instrumentation have been so rapid and extensive that they actually have kept ahead of the ability to utilize them fully in combustion research.

The instrument problem is complicated in engine studies by the fact that the radiation emanating from the cylinder gas varies rapidly during the engine cycle. To meet this problem two techniques have been used. By using fast-responding lead sulfide and photomulti-

plier detectors, the radiation is recorded on an oscilloscope as a function of time in the engine cycle for each wavelength, and readings of intensity at a given time in the cycle are made with point-by-point changes in the wavelength. When using the slower response thermocouple detector, it has been necessary to integrate the radiant energy over the period of the engine cycle.

In the case of the laboratory burner and jet engine studies standard recording techniques are used. In each case the basic information sought is the spectrum of the radiation emitted. The only exception is in the case of the total radiant heat transfer study in jet engines. In this instance the wavelength-dispersing optics of the spectrometer are dispensed with, and radiation of all wavelengths is allowed to fall on the detector at once. A single measurement suffices for each condition of operation.

Results from Specific Studies

In a paper of this scope it is impossible to present detailed results from involved research studies, since every such result must necessarily be subject to the most severe scrutiny and criticism before conclusions are reached. Reference, therefore, is made to other published literature for complete reports of the recent work done by the GM Research Staff[14, 15]. This paper can, however, indicate the general type of data obtained and the most general conclusions reached in brief portions of the work.

Gas Composition Studies of Preflame Reactions

Composition of the gases in preflame reactions produced both in a motored single-cylinder engine and in a laboratory burner has been studied by recording corresponding spectra in the two situations.

Records were made of the visible (and some ultraviolet) light emitted by engine preflame reactions and the burner second-stage cool flame. These were recorded with a photomultiplier detector. It was apparent that these spectra are very similar. In each case the emission represents radiation from high energy formaldehyde molecules. The formaldehyde is formed as an intermediate product of the reaction, and in the process of formation the formaldehyde is endowed with an excess amount of energy so that the light emission is actually chemiluminescence (Fig. 4).

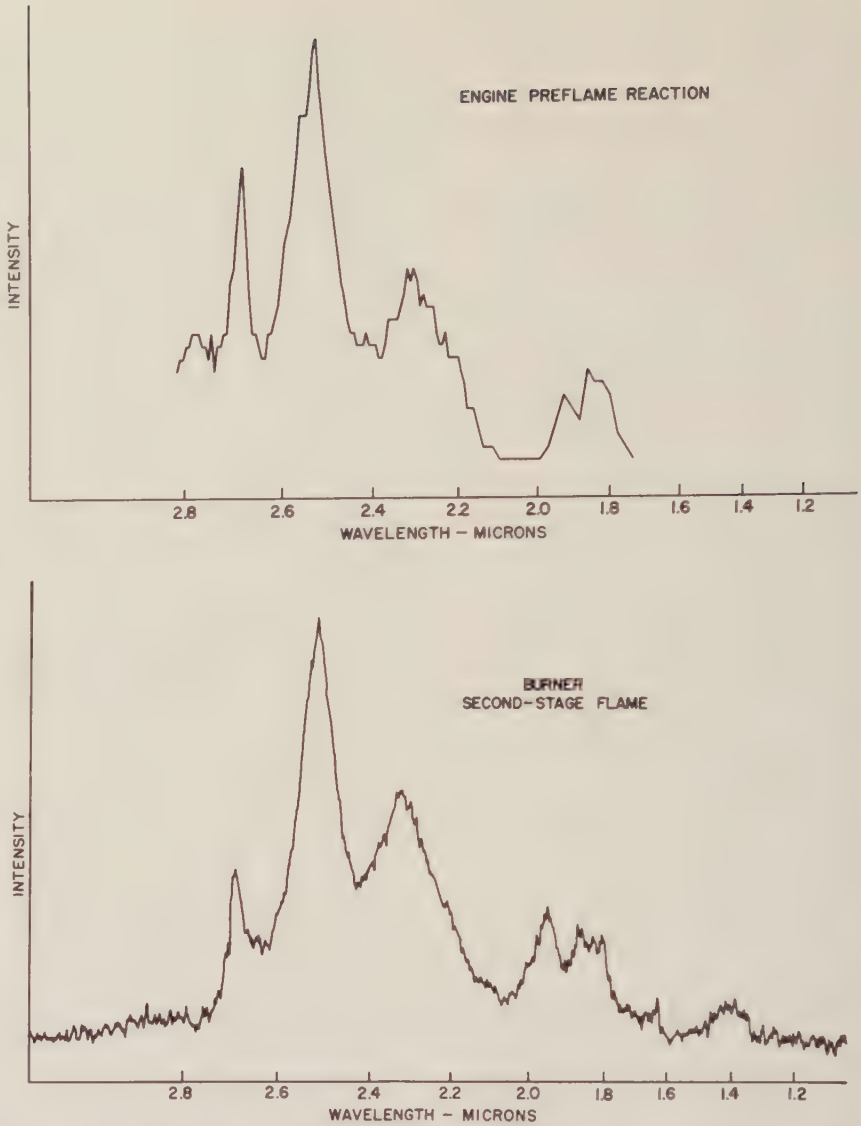


Fig. 5—The spectral records shown above compare the engine and burner second-stage reactions in the near infrared region of the spectrum. The band peaks at 1.4 and 1.87 microns are due to water vapor formed in the reactions. The two peaks at about 2.5 and 2.7 microns are from both H_2O and CO_2. The radiation at 2.3 microns has not been identified but probably results from some compound containing C-H bonds.

Other spectral comparisons between the engine and burner second-stage reactions were made in the near infrared region of the spectrum. Again the burner second-stage cool flame most nearly resembled the engine preflame reactions (Fig. 5).

More complete infrared spectra for the engine and burner have been recorded out to wavelengths of 11 microns or more. In these spectra a variety of intermediate and final products of the reaction appear, along with bands from the fuel itself. Although there are certainly similarities in these spectra which indicate a general similarity of the burner and engine reactions, still there are important differences which probably result from differences in the experimental conditions (such as pressure, fuel-air ratio) for the two cases. Additional spectra have been recorded for several different fuels, and it is the effect of changes in fuel composition and experimental conditions on the spectra which may be of help in learning how to control these important preflame reactions.

Temperature Measurements in a Jet Engine Combustor

Interest in making gas temperature measurements by radiation techniques first arose in connection with preflame reactions in spark-ignition engine end-

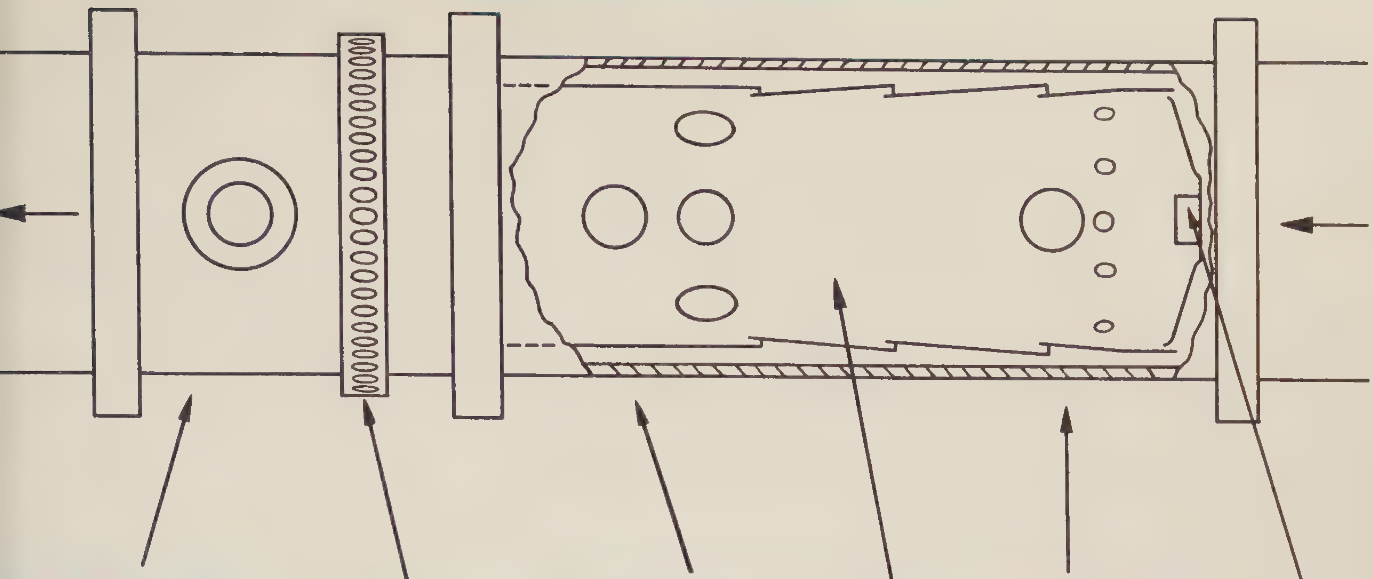


Fig. 6—Air enters the combustor from the right and mixes and burns with the fuel which is sprayed in through the fuel nozzle. Burning is essentially complete at the turbine inlet location, and in this region steady-state thermocouple and radiation measurements may be correlated. Combustor gases are viewed through the three windows indicated on the diagram. The near infrared spectrum obtained is much like that in gasoline engine flame.

gases. However, the project shifted to jet engine combustors when more immediately urgent problems appeared there. The inadequacy of thermocouple measurements was seriously impeding the combustor development programs for new high-powered jet engines.

Of the several techniques for measuring radiation temperatures, which have actually been applied at the Research Staff, the infrared two-color emission method appears most suitable for jet engine work. This method is based on the following mathematical relation:

$$\frac{E_1}{E_2} = \frac{\varepsilon_1}{\varepsilon_2}\left(\frac{\lambda_2}{\lambda_1}\right)^5 \frac{e^{\frac{C_2}{\lambda_2 T}} - 1}{e^{\frac{C_2}{\lambda_1 T}} - 1}$$

where

E_1 and E_2 = the emission intensities at two wavelengths (arbitrary units)

ε_1 and ε_2 = the emissivities at the two wavelengths (dimensionless)

λ_1 and λ_2 = the two wavelengths (microns)

e = 2.71828

C_2 = a universal constant = 25,893 microns (°R)

T = the absolute temperature of the emitter (°R).

This relationship is obtained from Planck's equation for blackbody radiation and applies to any radiating substance in thermal equilibrium. If the ratio of the emissivities at two wavelengths is known and if the ratio of the intensities is measured, the temperature can be calculated.

Measurements have been made at three locations in a single jet engine combustor set up on a test stand at the Allison Division (Fig. 6). The near infrared spectrum obtained from the jet engine combustor gases at the turbine inlet position is much like that from the gasoline engine flame. The emission peaks all result from H_2O and CO_2 formed as products of combustion.

Temperature measurements were made from the two water vapor band peaks at 1.89 and 2.55 microns.

Several practical experimental difficulties, however, still existed in making these temperature measurements, and the scatter in the data obtained may be attributed to these difficulties (Fig. 7). The presence in the spectrum of small amounts of radiation from the burner walls reflected into the spectrometer by the window surfaces is one difficulty which was detected and is now being eliminated. Carbon formation in the flame under some conditions is another complication. The flame spectrum, recorded under conditions of considerable carbon formation, leaves the water vapor bands completely unsuitable for two-color radiation temperature measurements. Fortunately, temperature measurements can also be made from the carbon spectrum itself; however, recalibration with different wavelengths is required.

In general, the preliminary data are most encouraging and point the way to the development of a convenient, rapid-recording radiation temperature detector for use in jet engine combustors. Such a device will be most useful because of its ability to follow rapidly fluctuating temperatures and because it will not disturb the environment in which the combustion reactions occur.

Summary

The combustion process in internal combustion engines has been the subject of intensive research at General Motors for over thirty years. During the course of this work many research techniques have been applied to unraveling the endless strings of relationships in this complicated phenomenon. Radiation techniques have contributed important information in the past and, therefore, are being exploited in many of our current combustion problems. Recent spectroscopic studies of combustion have been directed at the preflame reactions in a spark-ignition engine, at the very

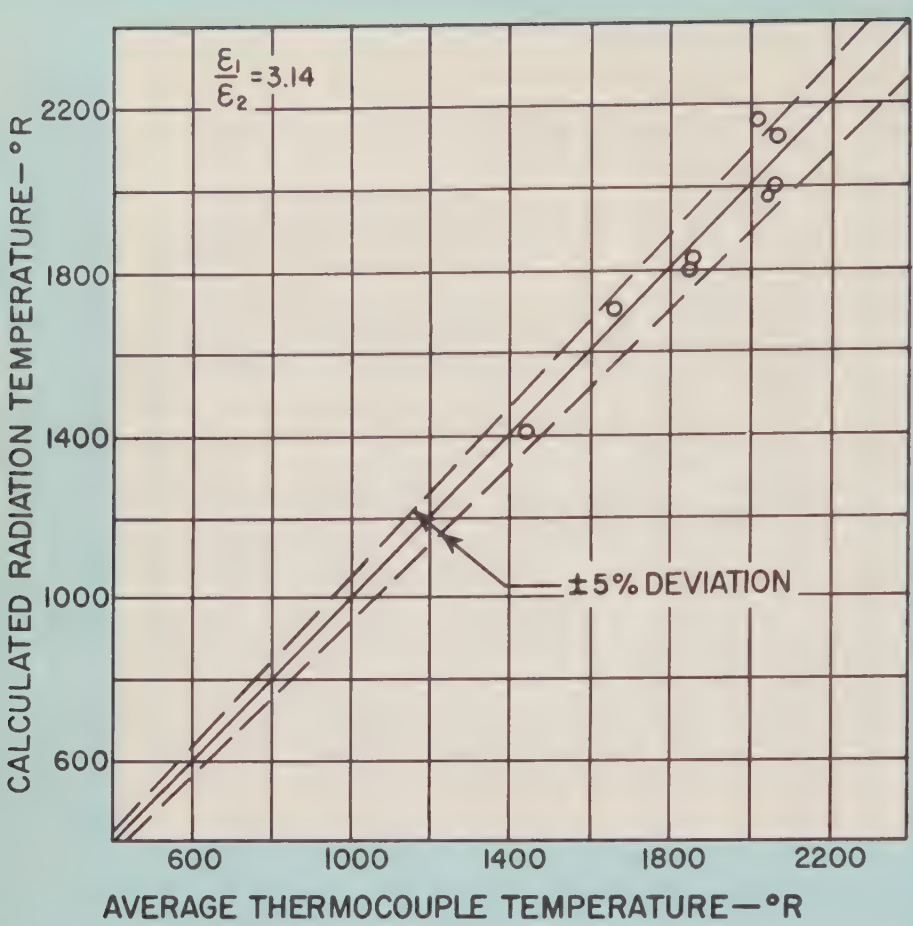


Fig. 7—Several practical difficulties existed in making temperature measurements of jet engine combustor gases, which account for the scatter in the data plotted above. These difficulties were due principally to the reflection of small amounts of radiation from the burner walls into the spectrometer by the window surfaces and carbon formation in the flame under some conditions.

similar cool flame reactions in a laboratory burner, and at the flame and products of combustion in a jet engine combustor. These studies have been aimed primarily at the composition and temperature of the gases in the flames, although measurements are also being made of total radiant heat transfer in jet engine combustors. Results obtained thus far appear to justify the means.

Acknowledgement

The writer wishes to express appreciations to Professor John T. Agnew of Purdue University, Consultant to the Fuels and Lubricants Department of the Research Staff, and to R. E. Donovan of the Physics and Instrumentation Department, Research Staff, for their continued contributions to the radiation combustion studies.

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Research Studies on Automotive Engine Fuel Economy

By DARL F. CARIS and
FLOYD A. WYCZALEK
General Motors
Research Staff

Increased compression ratio results in greater engine efficiency, power, and performance

In addition to important increases in engine power and performance since 1948, actual tank miles per gallon has increased 20 per cent. The most direct way in which efficiency can be improved still further is to continue increasing the compression ratio through chemical octane numbers built into the fuel and mechanical octane numbers built into the engine. In conjunction with this, combustion chamber design is a rewarding approach; some designs produce lower octane requirements by increasing the rate of combustion. Another factor to be considered in increasing fuel economy is the problem of deposits in the combustion chamber. By reducing deposit weight to a minimum, detonation and surface ignition effects can be substantially reduced and the octane requirements correspondingly lowered. General Motors research work on automotive engine fuel economy is part of the overall effort to improve the efficiency of automotive engines which has been carried on by the automotive and petroleum industries during the past years.

WIDE-SPREAD adoption of new high compression engine designs, whose predecessors were under laboratory tests a decade ago[1], combined with progressive improvements in automotive engine efficiency, has rapidly produced real savings in today's national fuel bill.

The fact that actual tank miles per gallon has progressively increased 20 per cent over 1948[2], integrated with the present annual national motor fuel consumption of 44 billion gallons costing 13 billion dollars, shows that it would cost 1½ billion dollars more to produce the power, performance, and economy of today's automobiles if we had to use the engine efficiency of the 1940s[3]. This saving in fuel cost is more than the price paid for all the coal and oil used by the public utilities and railroads in the United States during 1955[4].

From each individual automobile owner's viewpoint this saving amounts to a direct daily refund, since an average driver will pay for and use two gallons of motor fuel a day. It is clear why automotive engineers consider the development of more efficient engines to supply today's power and acceleration requirements one of their most important objectives.

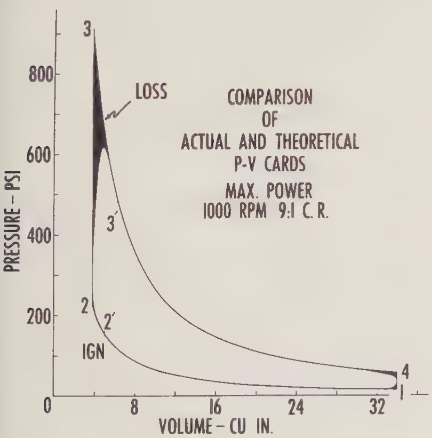


Fig. 1—This graph shows a theoretically and an experimentally obtained pressure-volume plot for a typical automotive cylinder. The area of such a card is a measure of indicated work. Note that the unshaded area, which is the actual work of the automotive cycle, represents more than 90 per cent of the total theoretical card 1-2-3-4. The theoretical area was obtained by extrapolating the compression and expansion curves at an exponent of 1.3. This is the measured effective exponent produced by the automotive engine.

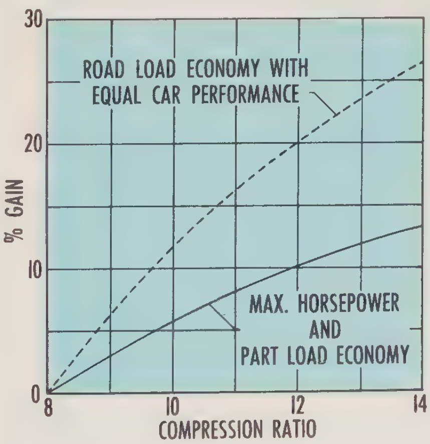


Fig. 2—By increasing the compression ratio, engine efficiency is improved. The solid curve shows the actual maximum power and part-load economy gains which can be obtained experimentally over an 8 to 1 compression ratio engine. The dashed curve shows the increased gains obtained by exchanging power improvement for economy with car performance matched by using lower axle ratios.

Compression Ratio—The Key to Efficiency

The thermodynamic principles of the Otto cycle, upon which the automotive engine is based, are such familiar territory to the engineer that it is possible not only to predict precisely the actual engine processes but, also, to build engines which at optimum conditions will recover more than 90 per cent of the maximum expected indicated work. Knowing where and to what extent the automotive engine deviates from theory is essential to the direction of corrective design and proper evaluation of experimental results (Fig. 1).

Although there are other less basic mechanical methods to improve efficiency, in keeping with today's power and performance requirements the most fundamental way is to continue increasing the compression ratio. As is well known, higher compression ratio increases both maximum power and economy. Therefore, in an automotive installation if desired this power improvement can be exchanged for an additional economy gain if car performances are matched by using lower axle ratios (Fig. 2).

Chemical versus Mechanical Octane Numbers

There are two factors which allow compression ratio to be increased:

(a) Chemical octane numbers built into the fuel by the petroleum refiners

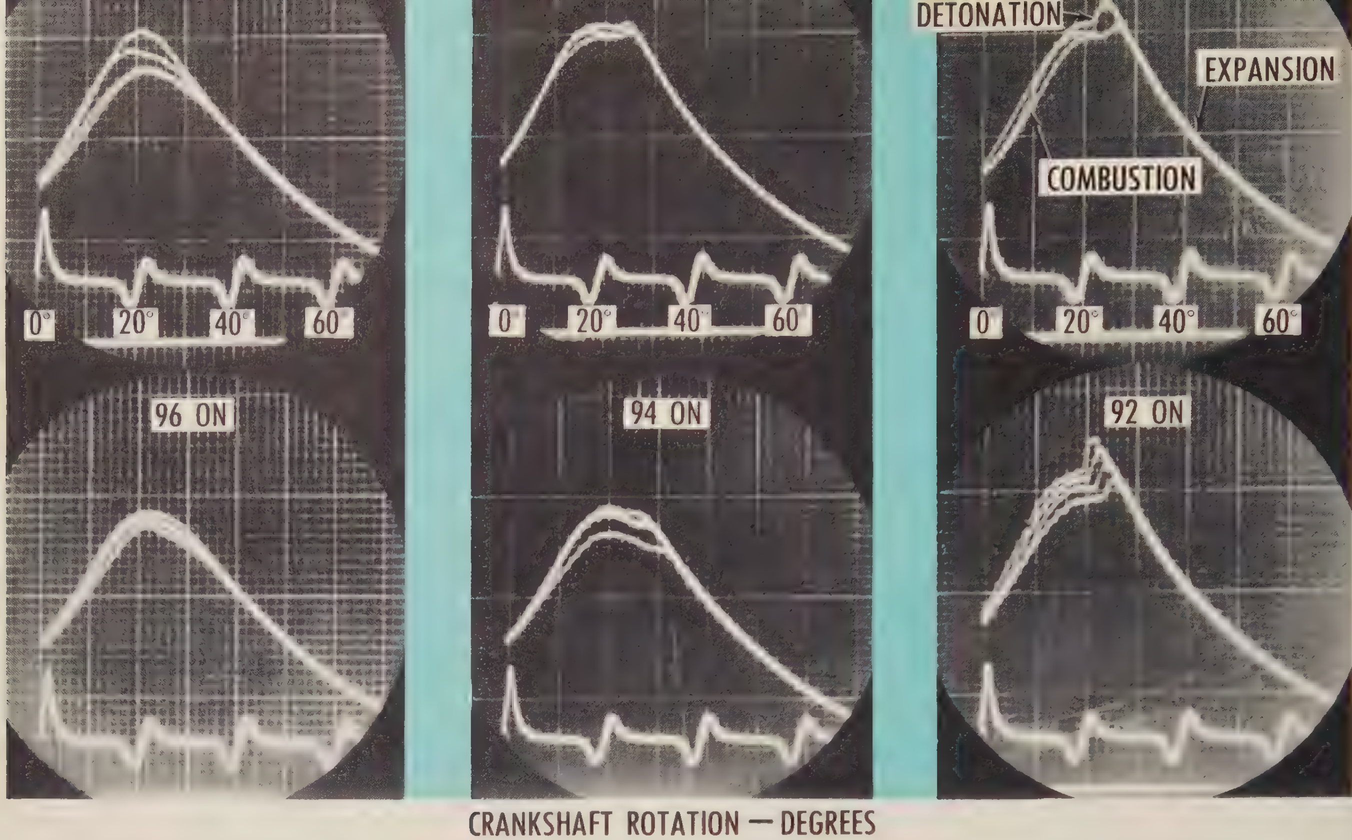


Fig. 3—These oscilloscope curves show typical detrimental effects of reducing fuel octane number upon the combustion and expansion portion of an engine's pressure-time indicator card. These test examples were taken from a production V-8 engine at an engine speed of 1,000 rpm, 9 to 1 compression ratio, 99 per cent power spark advance of 14°, and full throttle operation. The time axis is calibrated in crankshaft degrees after top-dead-center. Detonation, the distorted portion near the peak pressure of the cards, increases severely as fuel octane number is reduced from 96 to 92.

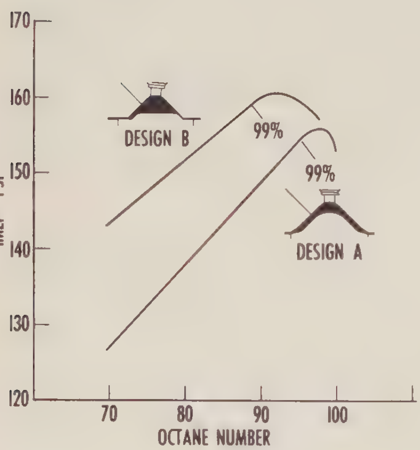


Fig. 4—These curves demonstrate the extent of the roles played by both chemical and mechanical octane numbers in determining specific power. The detonation-limited power obtainable, expressed as IMEP, is plotted at 2,000 rpm, 9 to 1 compression ratio, using primary reference fuels. The fuel required to produce 99 per cent of maximum power for Design *A* is 96 octane number; substantially higher octane fuels could not be effectively utilized in this case. Design *B*, however, produced more power on a given fuel and, therefore, is said to have mechanical octane numbers. Design *B*, which has a 99 per cent power octane requirement of 89, will operate satisfactorily at a higher compression ratio when the 96 octane number fuel required by Design *A* is used.

Fig. 5—Examples of the effects of combustion chamber design upon mechanical octane numbers are shown by these scale cross-section drawings through various chambers. These tests compare the octane requirements at 99 per cent power spark settings, 1,000 rpm, and 9 to 1 compression ratio. As can be seen, Design *B* has a 22 octane number advantage over Design *A*. Design *D* has more than a 9 octane number advantage over Design *C*. This means that with a given fuel quality, Designs *B* and *D* can be operated at a higher compression ratio to produce better efficiency and power.

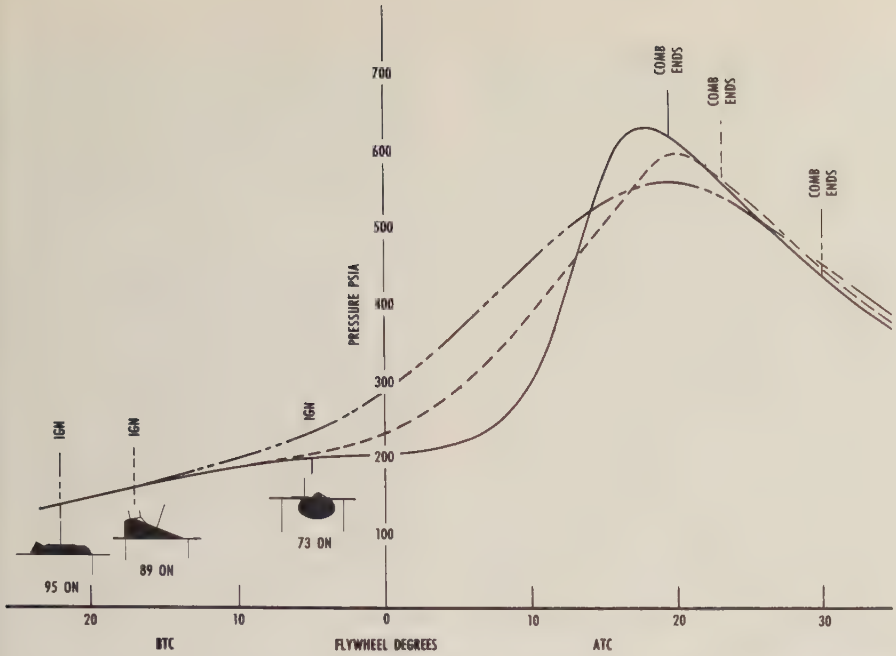


Fig. 6—These curves summarize the combustion periods and show the minimum and maximum pressure-time effects which have been observed after studying many designs. The initiation and the end of combustion are shown for the three cases. It is apparent that the total combustion period is reduced for the low octane requirement combustion chambers. The corresponding 99 per cent power octane requirements are indicated below each design. These balanced diaphragm-indicator results were obtained at 1,000 rpm, 9 to 1 compression ratio, and MBT spark settings.

(b) Mechanical octane numbers built into the engine by the engine designers.

Chemical octane numbers increase engine efficiency by allowing detonation-free operation at higher compression ratios. When the fuel octane number is decreased, detonation increases severely (Fig. 3). In addition to power losses, this is the fundamental cause of the audible sound commonly called "knock." The effect which is of prime importance is that fuel octane number determines the knock-limited power of an engine (Fig. 4A). On the other hand, some combustion chamber designs produce more detonation-limited power on the same fuels (Fig. 4B); these designs are said to have mechanical octane numbers. There are many other well known factors, such as improvements in ignition control, carburetion, valve timing, and transmissions, which are important in the development of mechanical octane numbers. The least predictable but most basic field, however, is the combustion period of the Otto cycle. Even though combustion represents less than 10 per cent of the cycle, its control through chamber design is the most promising area for future development[2].

Fast-Burn Combustion Controls Detonation

The design of the chamber has a definite effect upon the 99 per cent power octane requirements of the engine (Fig. 5). In order to understand why various designs differ so radically in performance one approach is to evaluate the many physical characteristics which have been changed, such as compressive turbulence, flame travel, concentration of the charge at the point of ignition, and surface quenching effects. By studying the combustion periods of many experimental chambers, however, it was found that the net result of those physical design changes which produced lower octane requirements was a substantial increase in the

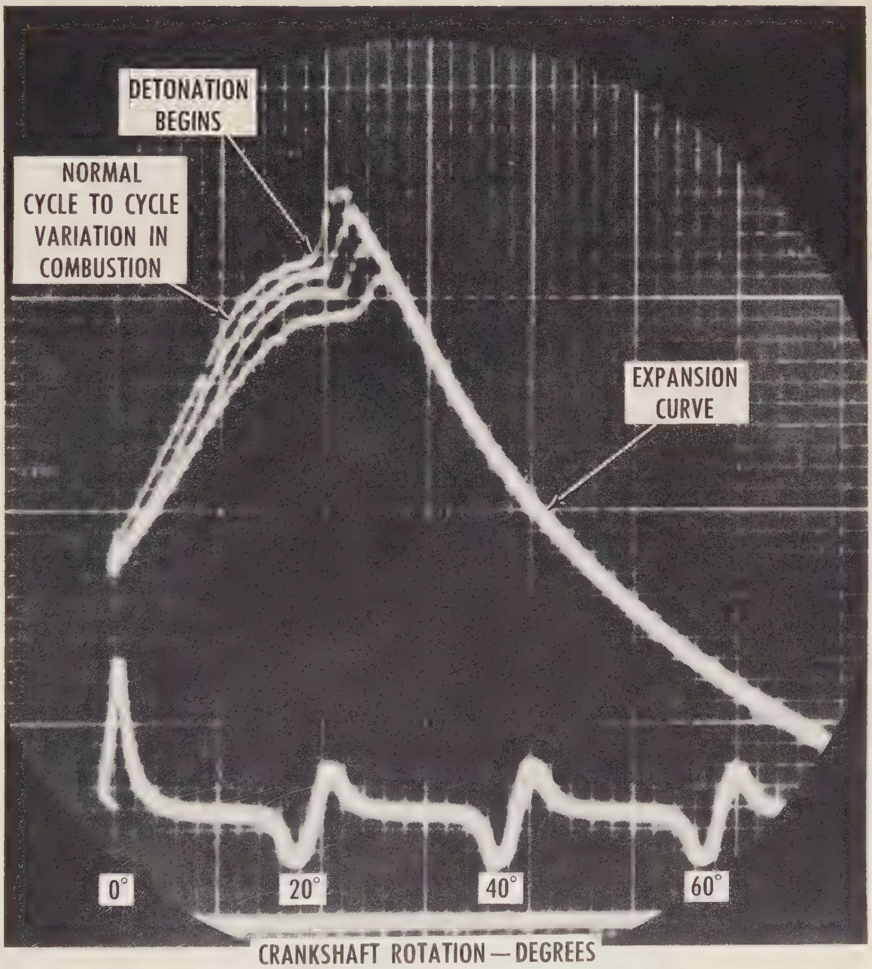


Fig. 7—This photograph of portions of several consecutive engine pressure-time cycles shows the normal cycle to cycle variation experienced in a typical engine. The distorted portion at the peak pressure is caused by detonation. The multiple oscilloscope pressure traces show that detonation of the end gas occurs in a precise time relationship to increasing combustion pressures. These tests, under mild detonation conditions, were made at 1,000 rpm, 9 to 1 compression ratio, 99 per cent power spark advance of 14° using 92 octane commercial gasoline. The time axis is calibrated in crankshaft degrees after top-dead-center.

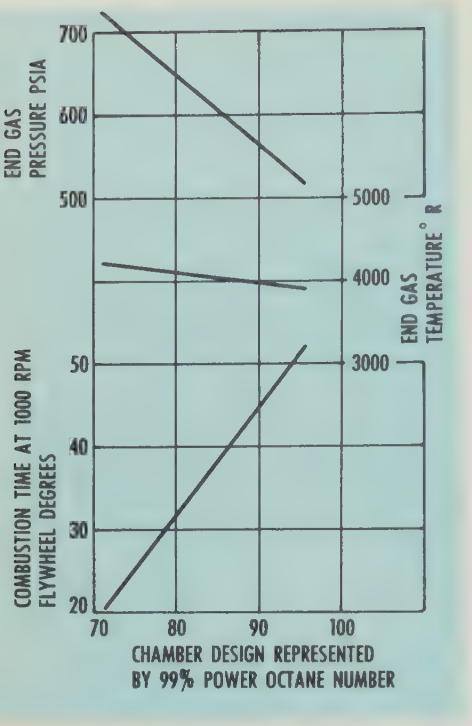


Fig. 8—A summary of the effects of combustion chamber design upon the fundamental factors of end gas temperature, end gas pressure, and total combustion time associated with designs of various 99 per cent power octane requirements shows that combustion time is the dominant factor which makes low octane requirement chamber designs possible. These results were obtained from balanced diaphragm pressure-time cards for many experimental chamber designs at 1,000 rpm, 9 to 1 compression ratio, and MBT spark settings.

rate of combustion. A low octane requirement design is characterized by a low 99 per cent power spark advance and an early end to combustion (Fig. 6).

The fact that a precise relationship exists between end gas pressure and combustion time has been demonstrated experimentally (Fig. 7). The effects of combustion chamber design can be summarized in terms of these final, fundamental parameters of end gas temperature, end gas pressure, and total combustion time (Fig. 8). It is apparent that short combustion time, resulting from faster burning of the mixture, is the dominant consideration which allows some designs to operate satisfactorily on low octane fuels. Thus, it was possible to reduce combustion time by more than one-half and, thereby, achieve an important gain in mechanical octane numbers.

Combustion Chamber Design Factors

Specific octane requirement effects of the design changes which were guided by the above principles can be evaluated in terms of such design factors as flame travel length, compressive turbulence created by piston coverage, and charge concentration at the spark plug.

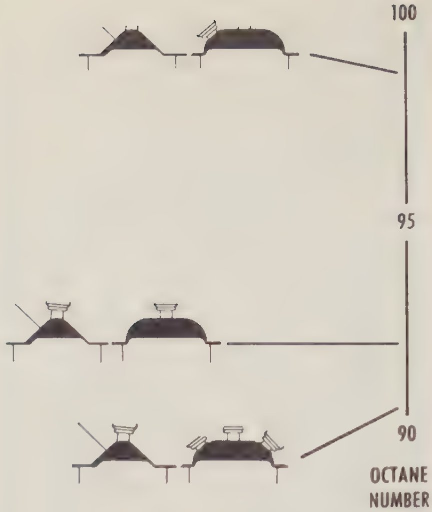


Fig. 9—This example shows the effects of flame travel length upon octane requirements obtained during developmental tests conducted on an experimental version of the 1954 Buick chamber[5]. The results were obtained at 1,000 rpm, 9 to 1 compression ratio, and 99 per cent power spark.

Flame travel length was reduced by placing the spark plug in the center of the cylinder bore. This central spark plug location together with multiple ignition resulted in a substantial improvement in octane requirements (Fig. 9).

Compressive turbulence was produced by utilizing piston motion together with properly matched piston and cylinder head surfaces. It is expected that such turbulence increases are in proportion to piston coverage. Increased piston coverage and the resultant concentration of the charge at the point of ignition produced a substantial reduction in the octane requirements (Fig. 10).

Concentration of the charge at the spark plug, in combination with turbulence, resulted in considerably lower octane requirements than when the charge was concentrated in the most remote portion of the chamber (Fig. 11).

The Problem of Combustion Chamber Deposits

One of the major problems common to all combustion chamber designs is deposits. In addition to many other undesirable results, the presence of deposits causes detrimental detonation and surface ignition effects. These normally increase the octane requirements of the engine.

Fig. 10—These two chamber designs compare the effects of piston coverage on octane requirements. It is apparent that increased piston coverage together with the resultant concentration of the charge at the point of ignition, as seen in the lower chamber design, produce a substantial reduction in the octane requirements. These results were obtained at 1,000 rpm, 9 to 1 compression ratio, and 99 per cent power spark.

Detonation effects are well known to the engine designer and have been thoroughly studied. It is common practice to design an engine for a lower compression ratio than would be possible with a clean chamber to compensate for the detonation effects of deposits (Fig. 12).

Surface ignition effects have been receiving considerable systematic attention in recent years. Surface ignition is, essentially, an event caused by certain

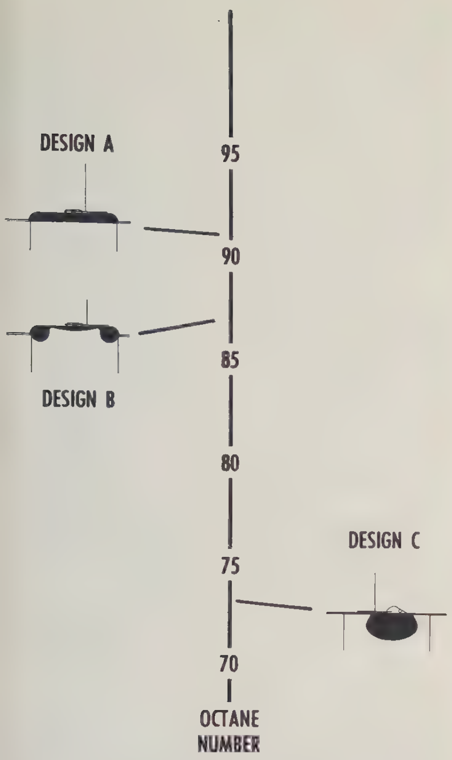


Fig. 11—The effect of concentrating the charge at the point of ignition in combination with turbulence is shown here in comparison with concentration in the most remote portion of the chamber. Both Designs *B* and *C* generate compressive turbulence by matching part of the piston and head surfaces. Design *C*, however, concentrates the charge at the spark plug, showing an improvement of 14 octane numbers over Design *B*, which concentrates the torus-shaped charge in the most remote portion of the chamber. Design *A* is included as a baseline to evaluate the turbulence effects of the other two chamber designs. The results were obtained at 1,000 rpm, 9 to 1 compression ratio, and 99 per cent power spark.

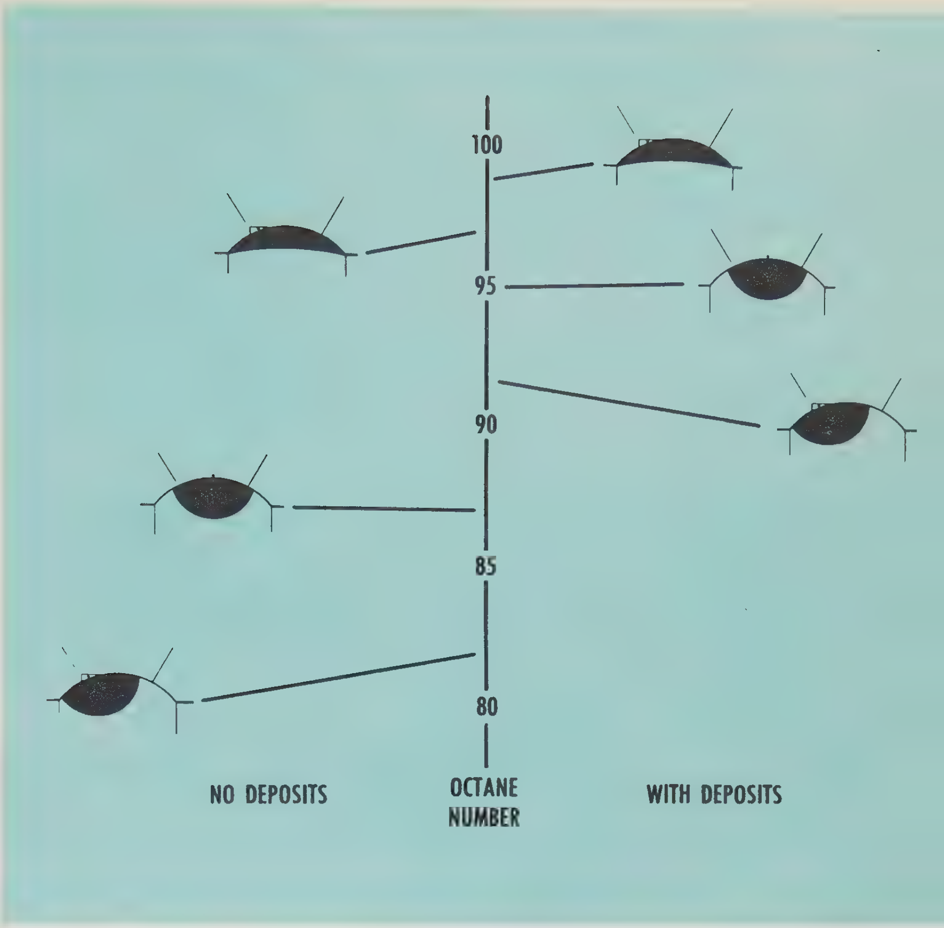


Fig. 12—The results of testing three chamber designs with and without deposits is illustrated here. The detrimental detonation effects of combustion chamber deposits upon octane requirements is shown at the right half of the figure. These tests were obtained at 1,000 rpm, 9 to 1 compression ratio, and 95 per cent power spark.

types of chamber deposits. Basically, deposit particles initiate random flame fronts before or after distributor-controlled ignition occurs. The most readily recognizable forms of surface ignition and the easiest effects to study in their natural environment are audible "run-on" and "wild ping."[6] Under these abnormal combustion conditions not only is precise combustion control required for good mechanical octane design practice lost to the designer, but severe physical damage to the engine can result. Whether or not the deposits reach the state in which they are able to initiate a random flame front depends upon the length of time they are subjected to the stressing action of the combustion chamber's pattern of gas temperatures and pressures and the characteristics of the deposits.

Engine operating variables, therefore, exert a major influence in determining whether a chamber design is primarily

OCTANE REQUIREMENTS UNDER SURFACE IGNITION CONDITIONS

Percentage of Maximum Power	99%	90%	70%
Distributor Spark Setting	[illegible]	[illegible]	[illegible]
Octane Requirements	[illegible]	[illegible]	[illegible]
Percentage of Surface Ignition	15%	100%	100%
Percentage of Detonation	85%	0%	0%

Table I—Distributor spark advance determines whether detonation or surface ignition establishes the commercial fuel octane number required for satisfactory operation of a combustion chamber. At 99 per cent power spark settings the octane requirements were found to be primarily detonation limited. When distributor spark was retarded, frequency of surface ignition increased, until at 90 per cent power spark setting the octane requirements became 100 per cent surface-ignition limited. The 90 per cent power spark advance has been used, therefore, in tests when pure surface-ignition limited octane requirements are desired. Results are for a production combustion chamber at 2,000 rpm. 8 to 1 C.R.

OCTANE REQUIREMENTS UNDER SURFACE IGNITION CONDITIONS

Percentage of Maximum Power	[illegible]	[illegible]
Distributor Spark Setting	14	[illegible]
Octane Requirement	[illegible]	[illegible]
Percentage of Surface Ignition	10%	100%
Percentage of Detonation	90%	0%

Table II—Under some surface-ignition deposit conditions, retarding the spark from a 99 per cent power setting to 90 per cent power results in a slight increase in octane requirement, rather than decreasing the required octane number as would be expected from Table I. At 99 per cent power spark this engine design is primarily detonation limited with 90 per cent of the engine's noise failures resulting from detonation. At 90 per cent power spark the engine's audible failures, however, were due entirely to surface ignition. A higher octane commercial fuel was required to suppress these surface-ignition effects than the 99 per cent power detonation-limited commercial fuel octane requirement. Results are from a production-type design at 1,500 rpm, 10 to 1 C.R.

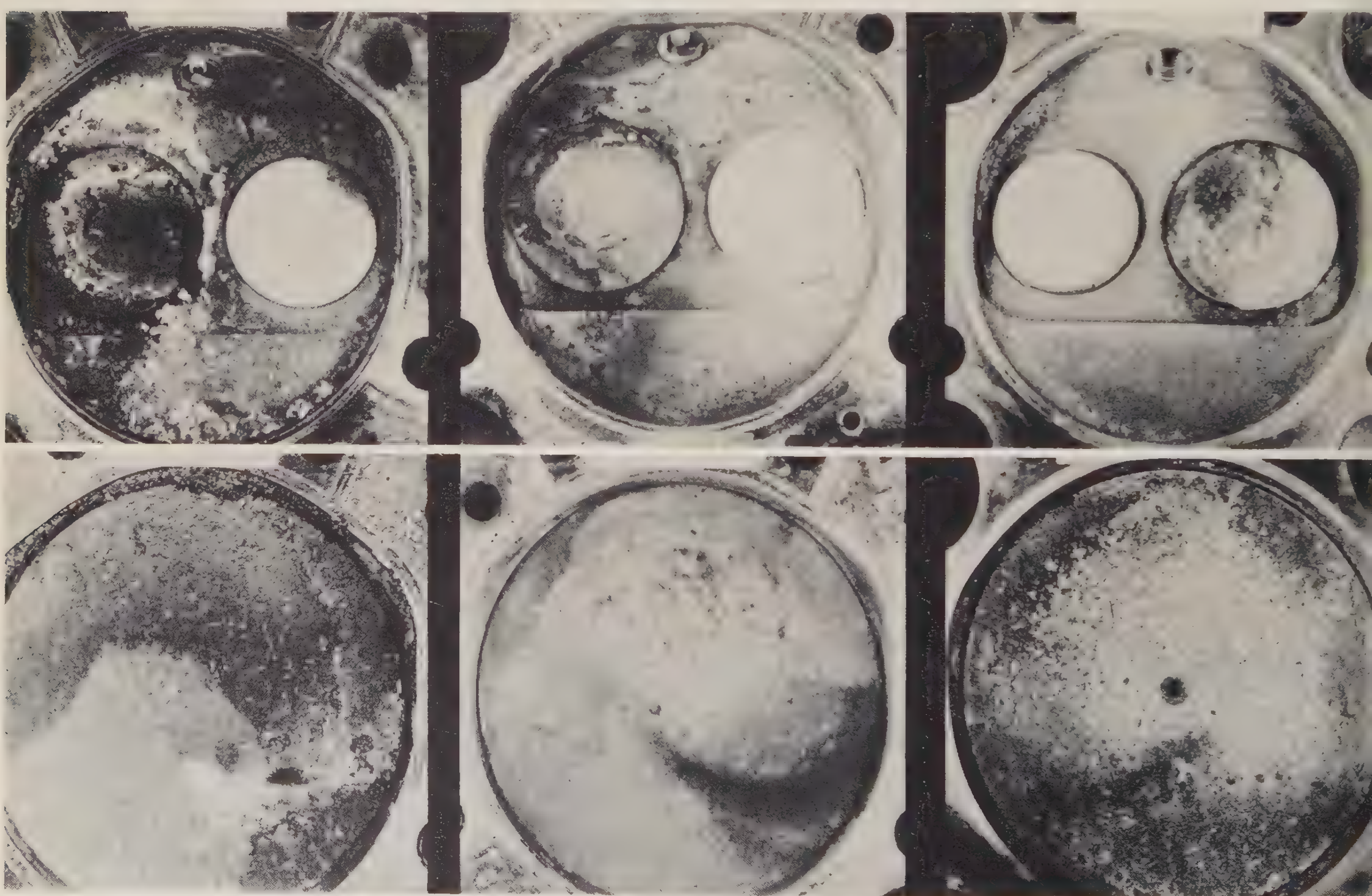
Table III (right)—Penalties in higher octane requirements are paid for the presence of chamber deposits, and much can be gained by reducing deposit weight to a minimum. These test results were obtained at 99 per cent power spark, 2,000 rpm, 8 to 1 compression ratio.

EFFECT OF DEPOSIT WEIGHT

Deposit Weight—Grams	15.1	7.3	5.0
Octane Requirement	96.8	87.9	86.3
Percentage of Surface Ignition	15%	17%	8%
Percentage of Detonation	85%	83%	92%

detonation or surface-ignition limited. For example, distributor spark advance determines whether detonation or surface ignition establishes the octane rating of the commercial type fuel required for satisfactory operation of a combustion chamber. At 99 per cent power spark settings the octane requirements of most designs were found to be primarily detonation limited and, on the average, surface ignition was observed to occur during only 15 per cent of the test trials. When the distributor spark was retarded to less than 99 per cent power, however, the frequency of occurence of surface ignition increased until at 90 per cent power spark setting the octane requirements became 100 per cent surface-ignition limited. The 90 per cent power spark advance has been used, therefore, in tests when pure surface-ignition-limited octane requirements were desired (Table I).

It is normally expected that retarding the distributor will decrease the octane requirements of an engine. When surface-ignition-producing deposits are present in some designs, however, the engine will not respond to spark retarding in this expected manner. For example, under some surface-ignition deposit conditions, retarding the spark from a 99 per cent power setting to 90 per cent power will result in a slight increase in octane requirement. At 99 per cent power spark the design is primarily detonation limited with 90 per cent of the engine's audible noise failures identified as detonation. At 90 per cent power spark, however, the engine's audible failures were identified as due entirely to surface ignition (Table II). The octane number of the commercial fuel required to suppress these surface-ignition effects in some cases is higher than the 99 per cent power



HEAVY MEDIUM LIGHT

Fig. 13—This photograph illustrates the appearance of typical surface-ignition-producing chamber deposits and the effect of oil consumption upon the deposit quantity using a "wedge"-type combustion chamber. These deposits were generated by cycling the engine alternately from idle to part throttle until deposit build-up reached equilibrium. Chamber design and compression ratio also affect the weight of combustion chamber deposits.

EFFECT OF CHAMBER DESIGN AND COMPRESSION RATIO ON DEPOSITS AND OCTANE REQUIREMENTS

	DESIGN A		DESIGN C	
Compression Ratio with Deposits	7.5	9.0	8.7	11.6
99% Power Octane Requirements	90	98	90	98
99% Power Spark Setting	19°	17°	4°	3°
Deposit Weight—Grams	10.4	7.1	2.5	3.0

Table IV—Comparison of a slow-burn and a fast-burn combustion chamber design with the presence of deposits and with various compression ratios at 99 per cent power spark, 1,500 rpm is shown here. Design *A* is a slow-burn "pancake" design similar to the cross section of Design *A*, Fig. 11. Design *C* is a fast-burn "pot" design similar to the cross section of Design *C*, Fig. 11. Design *C* possesses an advantage of 1.2 compression ratios over Design *A* using 90 octane fuel and 2.6 compression ratios using 98 octane fuel. A turbulent, low spark advance, fast-burn chamber such as Design *C* also tends to reduce deposit weight.

detonation-limited commercial fuel octane requirement.

Deposit weight also affects the octane requirements (Table III), and the deposit quantity is related to oil consumption (Fig. 13).

Finally, combustion chamber design and compression ratio control the deposit-determined octane requirement and the characteristic type of deposits formed in an engine. For example, a fast-burn "pot" design possesses a distinct advantage over a slow-burn "pancake" design. Using 90 octane fuel, it has an advantage of 1.2 compression ratios. Using 98 octane fuel, it shows an advantage of 2.6 compression ratios (Table IV). There is, also, a tendency for deposit weight to be reduced with a turbulent, low-spark advance, fast-burn chamber.

Fig. 14—General Motors Research Staff has systematically evaluated many combustion chamber designs as one phase of a study directed toward improving automotive engine efficiency.

Summary

Observations based upon hundreds of laboratory experiments on combustion chamber designs in the last 10 years (Fig. 14) have resulted in systematic changes in engine design which have added mechanical octane numbers and helped make high compression engines satisfied with lower octane gasolines.

In engineering shop talk designs have been given such names as "bathtub," "undercut pot," "saucer," "pagoda," and "pancake." These designs have shown a wide difference in highest useful compression ratios and have helped establish fundamental design information for optimum improvement through combustion chambers. The tests demonstrated the advantages of compact, highly turbulent, fast-burn chambers in which the air-fuel mixture is burned before the chemical reactions that cause engine knock can occur.

The present success of the combined effect of both chemical and mechanical octane numbers is well illustrated by the tremendous forward strides in automotive engine power, performance, and economy over the last few years.

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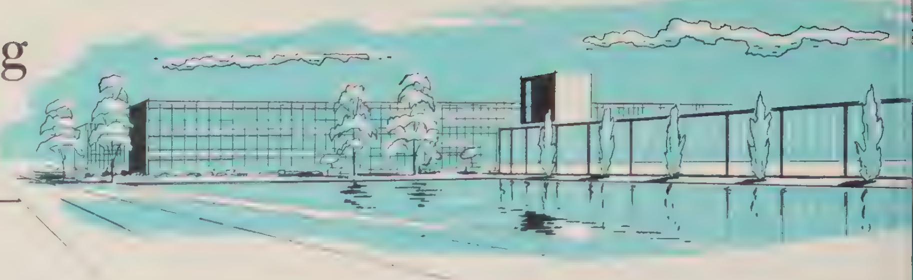
Product Engineering in General Motors



THERE are today in General Motors almost 25,000 employes engaged in product engineering developmental work. This may seem like a tremendous number, but even this total does not include personnel from many other engineering groups within General Motors not directly concerned with product engineering. Some of these other engineering groups work on the design and building of new tools and equipment, plant layout and construction, maintenance work, and power plant operation. Such activities are highly important; however, they are classified as manufacturing engineering, and I will, therefore, restrict this discussion to the product engineering organization with which I am more closely associated.

Maintaining a capable product engineering organization of the size found within General Motors is in itself quite a problem. The basic organizational scheme and operating philosophy of General Motors have established the pattern by which the product engineering groups operate.

Product Engineering in the GM Organization

General Motors was organized in 1908 around a nucleus of several companies with the idea of benefiting through mass production.

As General Motors grew it entered new product fields which, for the most part, were the results of GM's own research and engineering developments. In the early 1920s the organization and operating philosophy were established and essentially remain unchanged today. Both are very definitely related to the product engineering organization within General Motors.

The operating philosophy is based on the concept of the importance of people. Fundamentally, all business enterprises are composed of opportunities, facilities, and people. The opportunities for service to the public, as well as for profit, are there for anyone to grasp. The facilities always can be obtained if the required capital is available—and it usually is. Its people and their organization make a business enterprise unique.

Expressed in formal terms, the operating philosophy of General Motors is "decentralized operations and responsibilities with coordinated control." *Decentralization of operations and responsibilities* means dividing the job into as many pieces as is practical and placing an executive in charge of each piece with complete responsibility for its success or failure. *Coordinated control* refers to the formulation of overall policy and control of the flow of information. A two-way flow of information exists at each level of management—the downward flow from authority and the upward flow from initiative. A proper balance between these two flows is constantly sought in General Motors.

In accordance with the General Motors concept of decentralization, each of the 35 U.S. operating Divisions which comprise the line organization designs, develops, and merchandizes its own products. In addition, each Division has a separate engineering organization tailored to its own needs and has complete responsibility for the engineering of its own products. In addition to its own facilities, the Division has available the Staff facilities and the "know-how" of a central organization.

Staff operations are advisory and are available to assist the Divisions. That is the function of several engineering groups within General Motors today which have an overall responsibility to cooperate with Divisional engineering departments and to furnish advice and assistance as required. We do not pretend that our engineering organization is necessarily ideal, but we do believe it is the most effective for our purpose.

Objectives of Product Engineering

Our product engineering organization has three primary objectives: (a) to explore the future and to develop new products and new devices for eventual production and presentation to the public, (b) to develop new models which will succeed those now in production, and (c) to keep informed on the behavior of our products in the hands of our customers so that improvements and corrections can be made if required. Each of these objectives supports the overall General Motors objective—"more and better things for more people."

Naturally, in fulfilling these primary objectives in engineering, the multitude of products manufactured by General Motors requires extensive facilities and personnel. It would be well-nigh impossible for any one group to engineer products ranging from tiny ball bearings to Diesel locomotives—products which include all types of passenger cars, trucks and buses, earth moving equipment, household appliances, and electrical products, as well as defense products. Our decentralized Divisional operations coupled with coordinated control through the central organization has been the best way to carry out satisfactory engineering programs. To maintain an engineering organization dealing with such a wide range of products requires definite policy and control procedures.

Engineering Policy in GM

The control of engineering policy is by recommendation of an Engineering Policy Group which is advisory to the General Motors Administration Committee. The Engineering Policy Group reviews proposed major departures from current engineering practices suggested by the Divisions and also makes final recommendations on any new major engineering programs, such as new car models.

By CHARLES A. CHAYNE
Vice President
in charge of
Engineering Staff

There also is an interchange of engineering information between the Divisions by means of various committees. The most important of these from the engineering standpoint is the General Technical Committee which consists of the chief engineers of the car, truck, and body Divisions and the engineering executives of GM's Central Office Staffs. Regular meetings of the committee provide opportunities for the Divisional chief engineers to bring up problems of mutual interest and also to present their viewpoints regarding future engineering policy. This group also serves as a policy group with regard to the operation of the General Motors Proving Ground.

There also are Central Office Staff groups which supplement and assist the Divisional engineering programs. The Engineering Staff, Styling Staff, Research Staff, and the Process Development Section of the Manufacturing Staff are such Central Office activities.

Central Office Staff heads may deal directly with the executives in the Divisions. They do not, however, issue any instructions nor do they have any authority over the Divisions. The Divisions have an independent engineering responsibility, and the work of the Staff groups is independent of and supplemental to the work of the Divisional engineering departments.

Procedure manuals are an integral part of the coordination of effort between the various General Motors Divisions and Staff activities. Probably the three volumes of General Motors Engineering Standards, which are used by over 700 other manufacturing concerns, as well as by the entire General Motors organization, are the best known of these manuals. The Engineering Standards not only cover the uniform parts numbering system, standard parts numbers, and specifications for commonly used items such as nuts and bolts but also establish uniform specifications for a multitude of engineering and production materials and commonly used specialty parts.

A uniform parts classification which provides a uniform grouping system for the individual parts in complex assemblies, such as cars, trucks, bodies, and engines, makes it possible to compare costs, weights, service experiences, and warranty and policy costs between Divisions on a factual basis. Product Program submissions on new car models provide a uniform procedure for obtaining management review of new model proposals by the Divisions. Other procedures on car and body dimensioning, material analysis, and cross-indexing of industry specifications are also an assistance to the Divisions in dealing with matters on a uniform basis.

Engineering Personnel and Facilities

The product engineering organization is supplied with "new blood" by means of a formal program of hiring graduating engineers at various colleges and universities throughout the country. These graduates are referred to the engineering organizations within General Motors and are employed and trained by them in accordance with their particular needs. This is only natural because we have more than forty separate Divisional and Central Staff engineering organizations each of which concentrates on its own particular problems.

The hiring program for graduate engineers is based upon requests both from the Divisions and the Central Office Staffs. For example, this year General Motors requirements totaled over 1,400 graduates. To obtain these graduates the Central Office Salaried Personnel Placement Section visits approximately 125 colleges and universities across the country. The engineering graduates hired from this source are in addition to the 350 to 400 graduates coming annually from our own General Motors Institute. General Motors is particularly proud of the large proportion of its management that has come from its engineering organizations.

This issue of the General Motors Engineering Journal contains much information on the new Technical Center and its facilities. Other engineering and developmental facilities are also maintained by many of our operating Divisions. In fact, two General Motors Divisions recently have occupied new quarters located immediately adjacent to the GM Technical Center site. In a facility known as the Chevrolet Engineering Center, Chevrolet Motor Division has placed its personnel and laboratories devoted to research and engineering for its passenger cars, trucks, and other products. Fisher Body Division, likewise, has relocated its engineering and processing organizations—as well as its general offices—to the new site.

Allison Division—with headquarters in Indianapolis, Indiana—has underway a program involving an expenditure of more than 75 million dollars for facilities and forward developmental work on gas turbine aircraft engines.

Every effort is made to provide our engineers with the most modern, up-to-date laboratory and test equipment. When such equipment is not available from suppliers, we design it and build it ourselves.

I have purposely refrained from describing the engineering organization of other Central Office activities as these are described in detail elsewhere in this issue. I do, however, want to make some comment on the Engineering Staff of which I am in charge.

The primary function of the Engineering Staff is to carry on engineering development of benefit to all of General Motors. It is from this Staff group that will come many new engineering concepts, designs, and mechanical features of tomorrow's automobiles. Many of its engineering projects have to do with assisting the Divisional engineering departments. Other projects are years away from commercial application. Considerable expense, exploration, study, test, refinement, and engineering perfection still are ahead of us before these projects are successful in the form of products for our customers.

It is recognized by any sound engineering organization that with many developmental projects, there naturally will be some failures before success is achieved. Success in engineering is best assured by freedom of thought and expression. Freedom of thought comes from an engineering organization equipped with properly trained and educated personnel. Freedom of expression is obtained by providing the engineers with the best possible facilities to exercise, try out, and perfect their ideas. It is on this basis that engineering in General Motors functions in its role of providing "more and better things for more people."

Engineering Staff Facilities

Fig. 1—This view across the reflecting pool shows a portion of the Engineering Staff Administration and Shop buildings at the General Motors Technical Center. It is in this atmosphere that highly trained engineers with up-to-date facilities conduct forward, long-range developmental programs of value to General Motors as a whole, as well as assist the Divisions in their own engineering programs.

The Engineering Staff is one of the four Central Office Staff activities located at the Technical Center. The primary responsibilities of this Staff are two-fold: one, to carry on developments in product design in the area between the more basic, long-range investigations being done by the Research Staff and the immediate engineering work carried on by GM's manufacturing Divisions; and two, to provide a variety of engineering services to the various Divisions of General Motors. The Engineering Staff's facilities at the Technical Center consist of three buildings: the Administration Building which houses design and office groups; the Dynamometer Building which is equipped to handle a wide range of experimental testing; and the Engineering Shop Building which houses machinery and equipment for the construction and assembly of experimental models developed by the design groups.

A VISITOR'S first impression of the Engineering Staff facilities at the General Motors Technical Center might well be one of eye-catching appearance and architectural features. Yet beneath the building exteriors of extensive glass areas, brilliantly colored glazed brick, and porcelain enamel metal panels, the all important people, facilities, and operations are a measure of the value of such an establishment. The true importance of the Engineering Staff activity perhaps can be best developed by reviewing its objectives, its relationship to the rest of General Motors, its equipment and personnel, and some of its contributions.

The objectives of a central engineering activity were defined in a general way as early as 1921 in a resolution of the General Motors Executive Committee which reads as follows:

> "The question of having Mr. Kettering's Division function as the Engineering Department for some of the smaller divisions which do not have regularly organized Engineering Departments was discussed. It was the feeling of the Executive Committee that, while the Staff operations are entirely advisory, and responsibility for action rests upon the line Divisions; nevertheless, in the case of Divisions which are too small to justify functional departments, it might be possible for certain Staff groups to function for them."

At that time all of General Motors Central Office long-range developmental activities were concentrated in one group, under Mr. C. F. Kettering, which was known as Research and Engineering. It is interesting to note that then, as today, General Motors operations were decentralized with the Divisions having the primary responsibility for the engineering of their own products.

As General Motors grew and expanded, it became evident that additional Central Office research and engineering facilities were necessary and also that advanced engineering and styling could be handled to better advantage if separated from the more basic research investigations. As a result, there are now four separate Central Office technical groups dealing with long-range investigations and providing assistance to the Divisions as required. The Engineering Staff is one of these four activities and is itself divided into a number of independent groups carrying on two rather distinct types of activities:

By LYLE A. WALSH
General Motors
Engineering Staff

Freedom of expression contributes to rapid progress in product design

(a) Engineering Development—the development of product designs in the area between that done by the Research Staff and that carried on by the engineering departments of the Divisions

(b) Technical Services—the furnishing of miscellaneous engineering services of benefit to the various Divisions of General Motors.

Organization of the Engineering Staff

Only about one-third of the more than 2,400 people on the Engineering Staff are located at the Technical Center. The majority of the Technical Service Groups, such as the Proving Grounds, General Motors Photographic, the Patent Section, and the Engineering Standards Section, which furnish miscellaneous engineering services to the many Divisions of General Motors, have specialized facilities at other locations. While the Parts Fabrication Section is a Technical Service Group, specializing in the fabrication of exhibition and experimental models and low-volume wood, plastic, and sheet metal production parts for the Divisions, this group also does a great deal of work for the groups at the Technical Center and so is located on adjoining property.

The Technical Service Groups of the Engineering Staff located at the Technical Center include Vehicle Safety, New Devices, Technical Data, and the Canadian Operations Liaison Section. However, the majority of the Engineering Staff operations at the Technical Center are made up of the Engineering Development Groups and the Staff Services and Facilities Groups which support their work. The primary responsibility of the Development Groups is in connection with projects deemed to be important to all of General Motors—projects which may be some two to five years away from eventual production. These groups also assist the engineering departments of the Divisions in working on more immediate development problems.

In order to obtain most effective action, all phases of a project undertaken by one of these groups are under the direction of the head of the group. This involves preparation of estimates of project expenses; contact with other groups, both within and outside General Motors, to investigate design possibilities and to arrange for sources of experimental parts; and responsibility for making arrangements for all building and testing required to complete the project. This puts the entire responsibility for the new development in the hands of the group head, who thus has the maximum degree of freedom and flexibility in working out the problem, subject only to the direction of the Vice President in charge of the Engineering Staff and the limitations set on the project by the Engineering Policy Group. This freedom of operation contributes to extremely rapid progress in advanced design.

There are four Engineering Staff Development Groups: (a) Vehicle Development, (b) Suspension Development, (c) Transmission Development, and (d) Power Development. Vehicle Development is divided into two sections, Passenger Car and Automotive Ordnance.

It is the responsibility of the Development Groups to investigate novel or unique features of design which might ultimately provide the Divisions with an opportunity to make improvements in their products.

The Development Groups are assisted by the usual Staff Service Groups, such as Personnel, Accounting, Purchasing, and Building Services, as well as Machine and Test Facilities groups, in building and testing their experimental designs.

Buildings—Functional, Flexible, and Fashionable

The Engineering Staff buildings were the first to be occupied at the Technical Center. They were planned to provide the best possible functional facilities for the work to be done and arranged for maximum efficiency and safety. Particular emphasis was placed on flexibility of operation so necessary for long-range developmental work in many fields. In addition to providing buildings and equipment tailored to specific needs, much effort was also spent to provide a pleasant working environment best suited to creative effort.

An analysis of the needs of the Engineering Staff resulted in the construction of three separate facilities located in the southeast section of the Technical Center site.

Flexibility of floor-plan arrangements and facilities received first consideration in the design of each building, since the Engineering Staff's developmental programs are constantly changing and often require overnight rearrangement of offices, drafting rooms, shops, laboratories, and equipment. The key to this unusual flexibility is the use of modular construction in all buildings. The basic module is five feet. This type of construction applies not only to the building structure but also to lighting, heating, ventilating, and fire protection facilities, as well as wall partitions, door sections, and furniture units. With this standardization of buildings and equipment, it is possible to rearrange an entire department on an overnight basis.

The Engineering Staff quarters consist of three basic buildings: (a) Administration, housing design and office groups; (b) Shop, providing construction and assembly facilities; and (c) Dynamometer, equipped for experimental laboratory testing. All buildings are interconnected both above and below ground and are joined to other buildings at the Technical Center through underground tunnels.

Administration Building

The Engineering Staff Administration Building is a three-story structure containing over 93,000 sq ft of floor space (Fig. 1). Its unique structural features permit maximum flexibility of office and drafting room arrangement.

The special truss and exterior wall columns permit the use of the full width of the building without any obstructing columns. The arrangement of elevators, stairwells, and rest rooms on the south side provides a maximum of north light through the double-pane windows of heat absorbing glass. This arrangement, in combination with a new type of high-efficiency fluorescent lighting system, has resulted in excellent drafting room lighting.

Office furniture is also selected for

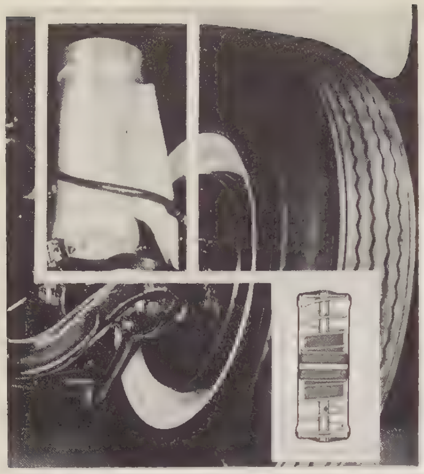


Fig. 2—This photo shows a unique harmonic damper mounted on the brake backing plate of a GMC light truck front wheel. The line drawing of a cutaway view of the road smoothing device shows the internal mechanism. Ringed by a felt pad, the metal weight is suspended between two springs. As the wheels bounce upward, the tendency of the weight to remain stationary reduces the vibrations that normally would be transmitted to the driver. Besides providing a comfortable ride, the damper also tends to keep the front wheels in contact with the road at all times, providing safer and more positive control. The harmonic damper is one of many engineering developments originating at the Engineering Staff at the Technical Center and adapted for use by General Motors Divisions.

maximum utility. Metal furniture with linoleum tops is used to provide a durable, efficient working surface which can be maintained easily. A special feature is the combination file and counter along the outside windows. The counter construction provides additional desk space with two-drawer files beneath, which are readily accessible from a seated position.

Shop Building

The Shop Building, located directly south of the Administration Building, is also designed for maximum utility, flexibility, and safety. The building has a floor space of over 146,500 sq ft. This area includes a partial basement. The building has a single row of columns at the center, and partitions along a central corridor are arranged so as to form a moveable wall which may be opened at any point to move vehicles or other equipment in or out of work areas.

To increase flexibility still further an extensive overhead crane system provides electric hoists at almost any point in the building. Water, air, and electrical outlets have been keyed to the modular construction of the building to insure maximum flexibility and to avoid needless expense and delays in departmental rearrangements.

Heating, air conditioning, and ventilating equipment for the Shop Building is installed in the basement and in three penthouses above the building's main corridor. Incoming air is filtered and supplied at sufficient pressure to prevent dirt from entering windows and doors

Dynamometer Building

The Dynamometer Building, to the east of the Engineering Shop, has a floor space of over 85,000 sq ft. This building was designed to provide facilities for the wide range of special tests encountered in developmental work and at the same time be sufficiently flexible so that individual test cells can be adapted for several different types of tests.

There are 21 cells primarily for engine and transmission work, as well as several special-purpose test rooms. A two-story test cell is equipped with power rolls and special recording equipment for conducting bump and shake tests on a complete vehicle, and a chassis test room with dynamometer test equipment that includes inertia weights and provisions for air blast and temperature control to permit the testing of vehicles under road conditions. A three-story test cell has facilities for maintaining a fluid flow of more than 2,000 gallons per minute for tests involving experimental hydraulic equipment. The Dynamometer Building also has a room large enough to accommodate a full-size vehicle which is completely shielded electrically. A special carburetor flow room is provided for fuel system developmental work.

A separate exhaust system is provided for each test cell. Intake air enters the room through the ceiling in the form of a curtain around the test area so that the operator is shielded from engine heat and fumes. Fuel tanks and gasoline blending facilities are located outside of the Dynamometer Building. Provision is made for supplying fuel to each dynamometer room at a pressure just sufficient to bring the gasoline to floor level. There is also provision for automatically stopping the flow of fuel from the Blending House in case of emergency. Both the Dynamometer Building and the Fuel Blending House, as well as all fuel lines, are protected by a built-in automatic CO_2 system as well as by hand CO_2 extinguishers.

Doors and windows of all dynamometer test cells are designed so as to function as emergency exits for people working in the test cells.

Specialized Facilities

Engineering equipment and tools are just as modern as the buildings. In addition to regular machine shop equipment, the experimental machine shop has specialized machines and inspection equipment capable of meeting tolerances of one ten-thousandth of an inch. Separate rooms are provided for grinding, heat treat, welding, and general machine work. Horizontal and vertical jig borers are enclosed in a temperature-controlled room. In the temperature- and humidity-controlled inspection department optical flats, having an accuracy of two-millionths of an inch, are used with helium monochromatic light for checking flatness. Also, in the Shop Building each Development Group has its own assembly area equipped with precision surface plates and motorized tools for the assembly of experimental parts.

Much of the instrumentation used in testing is designed and built by Engineering Staff personnel. Some of the more unusual equipment includes television cameras which can be mounted on the underside of a car to observe the action of chassis components while the car is traveling at high speed. Tiny plugs of radioactive cobalt are used in connection with a detector to measure the rotational speed of internal members of automatic transmissions. A special test machine evaluates automotive suspension devices and tires at wheel speeds up to the equivalent of 120 mph. A unique three-story waterfall produces a continuous stream of water eight in. in diameter, flowing at a speed of 30 mph, to test torque converter blade designs without the necessity of building a complete converter unit.

Some Engineering Contributions of the Development Groups

While these fine buildings and specialized facilities are important, the engineers who use them are even more important. The engineers on the staffs of the Development Groups represent 35 colleges and universities in 18 states and 13 colleges and universities in seven countries abroad. Their combined experience totals over 2,000 years of engineering knowledge. Their contributions are many and varied.

Fig. 3—The eight-foot horizontal flow table in the picture is one of the newer pieces of test equipment designed by Engineering Staff personnel for studies of fluid flow phenomena in torque converter blading. With a flow capacity of 1,500 gallons per minute, the fluid flow through experimental torque converter blades, 10 times actual size, can be studied in much the same way as scientists magnify objects and actions through a microscope. Injections of a black dye into the fluid flow permit engineers to study the effect of design changes in the experimental blades, evaluate their worth, and determine the next step in their unceasing search for improvement.

The Passenger Car Section of the Vehicle Development Group has designed, built, and tested many new and advanced passenger car designs. Some of the experimental cars designed and built by this group were put into production in the General Motors Adam Opel Plant in Germany, the General Motors Vauxhall Plant in England, and more recently the group did the preliminary design for the General Motors Holden car now being built in Australia. Other experimental cars of novel design continue to be built. In such instances it is not the intention to design a car which necessarily will be adopted for production by one of GM's car Divisions, but rather to investigate some new feature with the idea of developing fundamental information on the subject which will be of value to the car Divisions.

The Automotive Ordnance Section of the Vehicle Development Group has contributed to the nation's defense effort since World War II by doing design and developmental work on military vehicle components under government contract. This group did the preliminary work and built experimental models of several vehicles, both wheeled and track-laying, which were approved by Army Ordnance and later were produced in quantity by General Motors Divisions. More recently special light-weight track-laying vehicles have been developed by the Vehicle Development Group.

The Structure and Suspension Group contributed the preliminary developmental work on the independent wheel suspension systems adopted by General Motors in the early 1930s. Since then the group also has made many contributions to both civilian and military vehicle suspension developmental programs (Fig. 2). Some of the experimental suspension devices now under test look promising and may eventually supplant present production designs.

The Transmission Development Group designed and built preliminary models of the various types of automatic transmissions now being produced by General Motors. The group did similar work on ordnance transmissions and final drives for various military applications on both wheeled and track-laying types of vehicles. A number of experimental transmissions are presently being developed with the idea of making still further refinements in the automatic transmissions being manufactured by General Motors (Fig. 3).

The Power Development Section has contributed various engine design details to the car Divisions, as well as developing complete engines both for the armed services and for future consideration of General Motors Divisions. Recently this group has assisted in the development of passenger-car air conditioning and is working with several General Motors Divisions in developing better air conditioning and heating and ventilating equipment for the home.

Summary

The Engineering Staff is composed of four product Development Groups: (a) Vehicle Development, (b) Structure and Suspension Development, (c) Transmission Development, and (d) Power Development. Also a part of the Engineering Staff are such groups as the Proving Grounds Section, Patent Section, Parts Fabrication Section, Engineering Standards Section, New Devices Section, and the General Motors Photographic Section.

The success of the developmental projects already undertaken by these groups has resulted in an increasing demand for Engineering Staff services. The Engineering Staff is equipped with a wide variety of specialized engineering facilities and a staff of technical people whose combined experience totals over 2,000 years of engineering "know-how." All of the technical knowledge and skills of this organization can be quickly concentrated on any problem in product design.

Operating Principles and Applications of the Fluid Coupling and Torque Converter to Automatic Transmissions

By OLIVER K. KELLEY
General Motors
Engineering Staff

In recent years the demands of modern traffic have brought about a rapid increase in the installation of automatic transmissions not only in passenger cars but also trucks, buses, and other vehicles. To date successful automatic transmission design has been based on the utilization of a hydro-dynamic drive component—either the fluid drive coupling or the torque converter—in conjunction with planetary gears and hydraulic controls. The operation of an overall automatic transmission is quite complex and can not be understood easily. The hydro-dynamic drive component, however, is basically a simple hydraulic mechanism. An easy approach to an understanding of how the fluid drive coupling and torque converter perform their intended function in an automatic transmission is by using the principle of a spinning flywheel.

Mechanics of hydro-dynamic drive component based on spinning flywheel principle

In recent years no activity in the field of automotive engineering has been busier than that devoted to the development of automatic transmissions. By the end of 1955 General Motors had produced over 12 million automatic transmissions. Of this number approximately seven million were the well-known Hydra-Matic automatic transmission and the remainder were of the torque converter type. These figures represent passenger car installations only and do not include the thousands that have been installed on trucks, buses, ordnance vehicles, rail cars, and off-highway equipment. The automotive industry's production total of over 20 million automatic transmissions represents acceptance by the American motoring public of the convenience, ease, and safety of automatic drive.

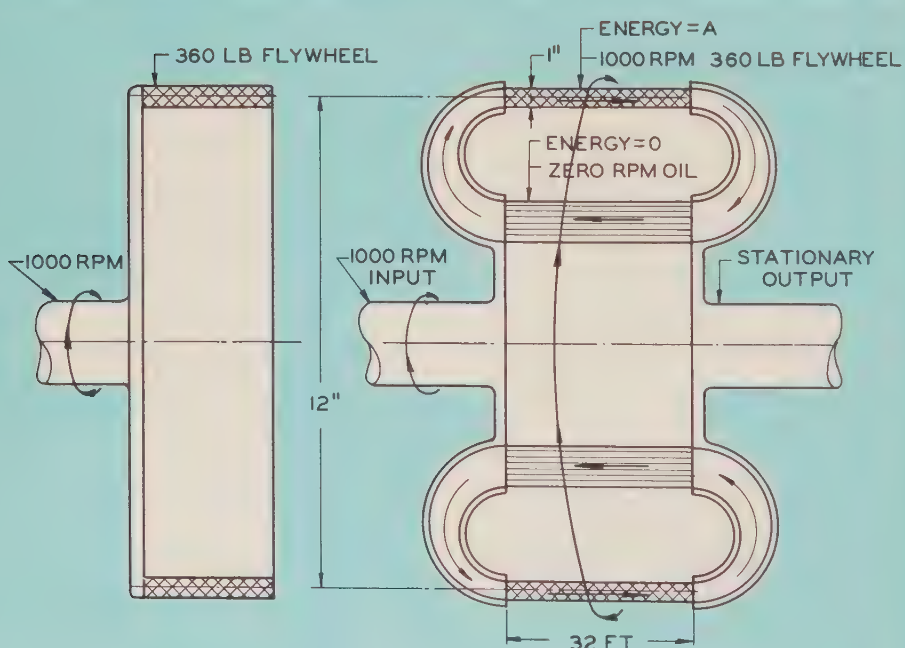


Fig. 1—A spinning flywheel, which exerts a turning force, or torque, on a mechanism stopping its rotation, parallels the operation of a fluid drive coupling which has its input member rotating and its output member stalled or stationary. If the input member of a fluid drive coupling extrudes out of its outlet, at a rate of 32 fps, a one-inch thick flywheel rim of oil rotating at 1,000 rpm, the turning force exerted each second on the output member to impart rotative motion will be 360 ft-lb.

To date successful automatic transmission design emphasis has been given to hydro-dynamic drive—either the fluid drive coupling or the torque converter. Each is basically a simple hydraulic driving mechanism, but despite their years of use and acceptance few people understand how they work.

The unique adoption and manner of combining the fluid drive coupling and the torque converter with full-power shifting gears can become complicated. In the same sense, the intricate designs of today's automatic transmissions keep the automatic transmission field very active. The basic mechanism of the hydro-dynamic drive component of an automatic transmission, however, is not as complicated as one might believe

Operating Principles of a Fluid Drive Coupling

The simple mechanics of hydro-dynamic drive begins with the principle of a spinning flywheel. A spinning flywheel has stored-up energy and, when stopped, exerts a turning force on the mechanism stopping its rotation. Conversely, a turning force must be exerted against the flywheel to get it up to speed again after it has been stopped. A fluid drive coupling with an engine driving its input member and its output member stalled or stationary is the direct equivalent of the spinning flywheel principle.

Oil flowing radially outward through the input member of a fluid drive coupling, which is simply a centrifugal pump, leaves in the form of a spinning flywheel rim—a flywheel rim made of oil. The turning force exerted by a flywheel while it is being stopped is a function of the rate at which it is being stopped, its mean diameter, and its weight. Assume that the input member of

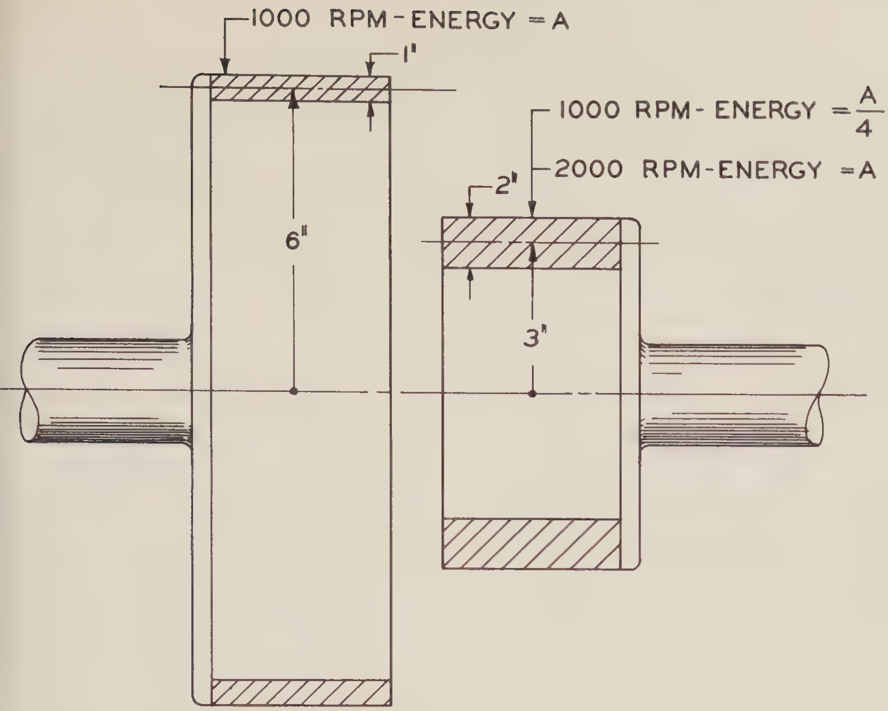


Fig. 2—Two flywheels, each rotating at 1,000 rpm and each weighing the same but with different mean diameters, contain specific energy characteristics. The energy contained in the larger diameter flywheel is four times greater than that contained in the flywheel of smaller diameter. Also, if both flywheels were to have the same energy, the flywheel of smaller diameter would have to rotate twice as fast as the larger diameter flywheel.

a fluid drive coupling extrudes out of its outlet, at a rate of 32 ft per sec, a flywheel rim of oil having a rotation of 1,000 rpm, a mean diameter of 12 in., and a rim section one inch in thickness (Fig. 1). The rotation of this spinning flywheel rim is being stopped by the stalled or stationary output member of the fluid drive coupling as soon as it emerges from the input member at a rate of 32 fps. A 32-ft length of such a flywheel rim of oil will weigh close to 360 lb and will produce a turning force of 300 ft-lb when stopped in one second.

The foregoing events take place in a fluid drive coupling at stall conditions when an engine developing a torque of 300 ft-lb and running at full throttle is trying to set a car in motion. The engine-driven input member is extruding a spinning fluid flywheel and pushing it into the blades of the stationary output member which stops the spin and in so doing receives a turning force on its blades amounting to a torque of 300 ft-lb.

Once the oil gets inside the blades of the stationary member, all resemblance to a spinning fluid flywheel is destroyed, and the oil merely comes out in a straight axial flow pattern and then returns again into the input member. There the oil is picked up from standstill and again re-created by the input member into a spinning fluid flywheel. An equal turning force, 300 ft-lb, must then be exerted by the engine against the oil while this is being done.

If the action of a fluid drive coupling running efficiently at higher speed is examined, another direct comparison with flywheels is recognized. Assume two flywheels, each running at 1,000 rpm and each weighing the same but with different mean diameters (Fig. 2). It is at once evident that the large diameter flywheel, while no heavier in total weight than the smaller one, is nevertheless more of a flywheel. If the diameter of the larger flywheel is twice as great as that of the smaller one, it is in reality four times the flywheel although no heavier in total weight. In other words, the energy contained in the larger diameter flywheel is four times greater than in the smaller

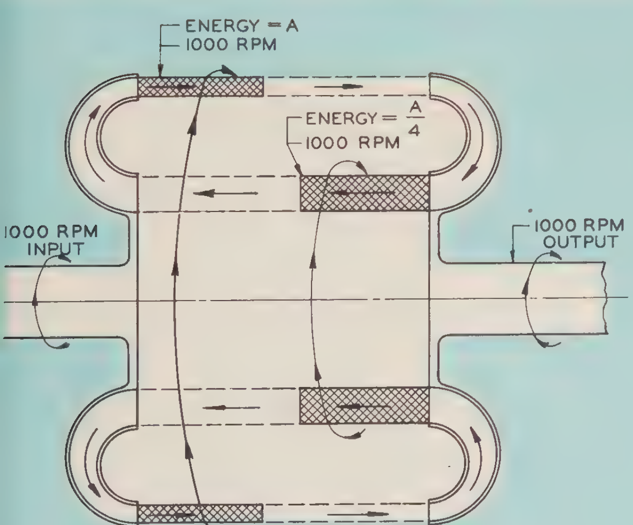


Fig. 3—The energy contained in the fluid leaving the output member of a fluid drive coupling is one-fourth the energy contained in the fluid as it entered the output member. The three-fourths of the total energy absorbed by the output member is used as the driving force of the fluid drive coupling.

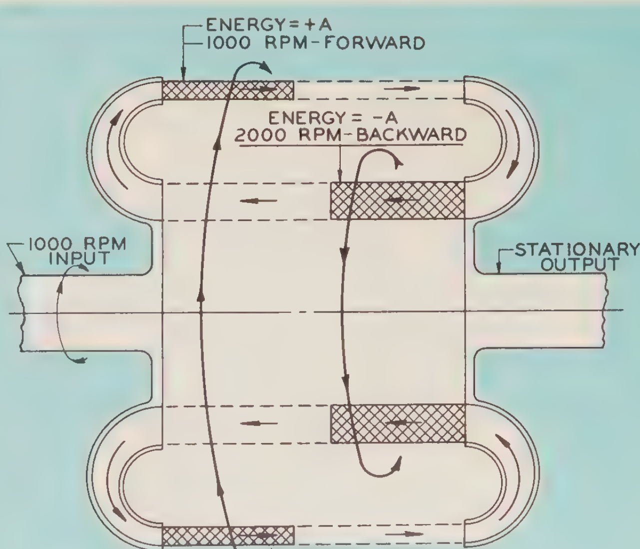


Fig. 4—If the straight blades of a fluid drive coupling's output member are replaced by blades that are strongly curved backward, the fluid leaving the output member will do so with a backward spinning motion which will cause a greater force to be exerted on the blades of the output member.

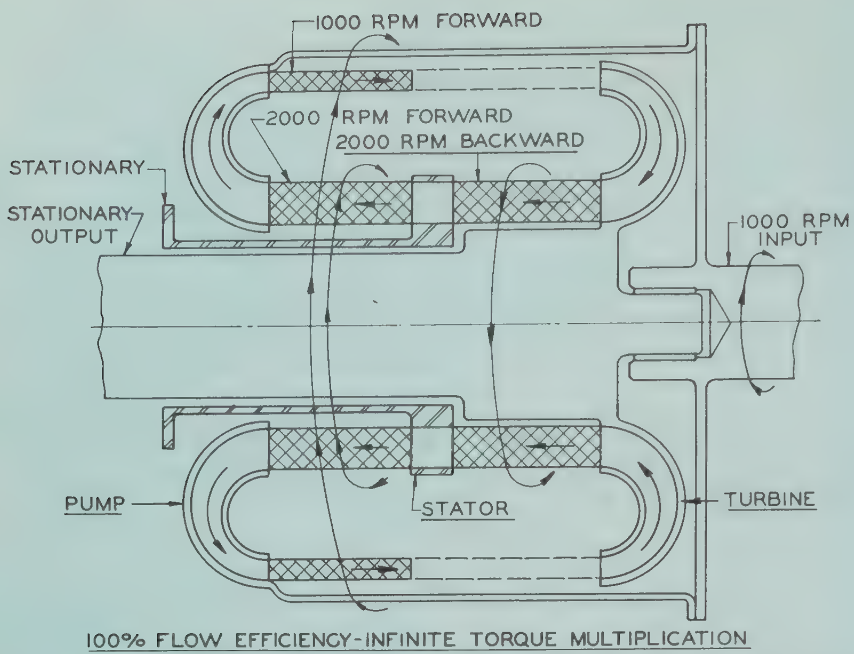


Fig. 5—If the blades of a fluid drive coupling's output member are strongly curved backward, the fluid leaves the output member with a backward spinning motion opposite in direction to the rotation of the input member it is to enter. If the fluid were allowed to impinge directly on the blades of the input member, an appreciable amount of energy would be required from the engine to stop the backward spinning motion. To correct this situation a stationary member, called the stator, is installed between the input or pump member and the output or turbine member. The stator serves to reverse the backward spinning motion of the fluid leaving the turbine so that it has the same direction of rotation as the pump it enters. The reactive force on the stator establishes the amount of torque multiplication developed.

diameter flywheel even though both weigh the same and run at the same speed. Another basic fact also can be recognized. If both flywheels were to have the same energy, the smaller diameter one would have to run twice as fast as the larger one.

If the metal of the 1,000 rpm flywheel of larger diameter could be efficiently extruded down to the diameter and proportions of the smaller diameter 1,000 rpm flywheel, the process would give the energy difference between the two flywheels. Three-quarters of the original energy of the large diameter flywheel would be left to deal with while the smaller diameter flywheel would still be available, weighing the same and spinning at the same speed. Such an extrusion process would be difficult in metal but is easily accomplished with oil. This is exactly what goes on in a fluid drive coupling while running near 100 per cent efficiency.

Assume a fluid drive coupling having a circulation efficiency of 100 per cent (Fig. 3). Under this condition the input or driving member produces a continuous flywheel at a specific number of ft per sec. The coupling's output or driven member, acting as an extrusion die, squeezes the fluid flywheel down to a smaller diameter with a correspondingly heavier rim section. This smaller diameter flywheel leaves the exit of the driven member at the same rpm as when it entered but minus three-quarters of its original energy. This three-quarters of the original energy drives the car and also must be re-supplied by the engine when the flywheel diameter is again extruded into a larger diameter after it enters the input member.

The fluid drive coupling, in its efficient driving range, can be considered as a pair of rotating extrusion forms which first make a large diameter spinning fluid flywheel into one of smaller diameter of equal weight and then vice versa. Energy is absorbed by the output member as the flywheel diameter is decreased, and an equal amount is spent by the input member as the flywheel diameter is increased.

Simple Three-Element Torque Converter

The basic operating principles of the fluid drive coupling aid in establishing the operating principles of a simple, three-element torque converter.

Assume, as before, that the circulation efficiency of the fluid drive coupling is 100 per cent, that the input member is rotating at 1,000 rpm, and that the output member is stalled or stationary. However, replace the straight blades of the coupling's output member with blades that are strongly curved backward and which, by proper bending, can be made to receive the spinning oil without splash. By having the exit of the blades strongly curved backward the oil, as it is finally extruded out of the output member, will now be spinning backward (Fig. 4).

The backward speed of the spinning fluid flywheel depends upon the exit angle of the blades and the flow velocity of the oil. Assume that 32 fps is a high enough flow velocity and that the blades have a strong enough back bend so that the outcoming oil has a spinning speed of 2,000 rpm. The smaller diameter flywheel running at 2,000 rpm has the same energy as the larger diameter flywheel running at 1,000 rpm. If the output member is standing still and the blades have done their work on the oil 100 per cent efficiently, it would be possible to have this condition of equal energies in the input and output oils. However, the energies would be in opposite directions.

The turning force now felt by the output member, also referred to as the turbine, is twice as great as it was in the fluid drive coupling at stall conditions when the input member is sending out an equal fluid flywheel at 32 fps. The turbine feels the turning force of slowing down the 1,000 rpm fluid-flywheel rim section at a rate of 32 fps and also feels the reaction to the speeding up of the reversely spinning flywheel of equal energy. Obviously then, this turbine feels twice the turning force of the fluid drive coupling for equal flow velocity and equal input member conditions.

One condition is seriously wrong, however, in this arrangement—the direction of the backward spinning oil leaving the turbine. It would require the entire engine torque just to stop this backward rotation when it hits the entrance to the input member, or pump, and there would be no engine torque left to get the oil re-energized into a forwardly rotating fluid flywheel at the outlet of the input member.

This situation can be corrected by

installing a set of stationary curved blades, called the stator, between the turbine exit and the pump (Fig. 5). The addition of the stator changes the fluid drive coupling to a simple, single-phase, three-element torque converter. The curved stationary blades of the stator must be properly shaped to receive the backward rotation of the oil, bring it to a stop, and then direct it to a forward rotation. If this is properly accomplished without loss by having a very efficient blading arrangement in the stator, there will be no energy loss in the oil leaving the stator. The stator has merely received a fluid flywheel running backward at 2,000 rpm, brought it to a stop, and then let it convert itself into a forwardly rotating fluid flywheel at 2,000 rpm. The action is very similar to that which took place in the turbine.

It might be good to study the action of this conversion from one direction of rotation to the opposite direction of rotation. Consider first that the flywheel effect of any spinning body is in reality nothing but the total sum of the momenta of all of its particles due to their velocity and that the momentum is not lost if the velocity is not lost. From this it can be seen that as the oil is slowed down in its rotation by the stator blades and all of its rotation stopped, it is really accelerated into an axial flow without losing its velocity. This same absolute velocity, then, is directed by the stator blades into a new rotary direction, and as the oil leaves the blades, it is once again a fluid flywheel of the same speed but different direction of rotation.

Now consider what happens when this oil re-enters the pump. The oil re-entering the pump is in the form of a smaller diameter fluid flywheel rotating at 2,000 rpm with the same energy and direction of rotation as the larger diameter fluid flywheel coming out of the pump at 1,000 rpm. This means that the engine does not add any energy to the oil. The engine-driven pump could be designed with properly shaped blades to receive the 2,000 rpm smaller diameter flywheel and let it expand in a free whirl into the larger diameter flywheel. During expansion, the rotative speed of the flywheel would decrease while its radius increases, which is the natural behavior of liquids in free whirl, until it came out of the pump at 1,000 rpm with its original energy intact and essentially without exerting a force on the blades.

Theoretically, it would be possible to get a big driving torque on the turbine without having to spend any of the engine's torque. This would actually be the case if there were no flow losses. With 100 per cent flow efficiency perpetual motion would exist. However, friction in the fluid's flow makes it impossible to obtain such an ideal result because of the flow losses involved in taking the oil flywheel of larger diameter and extruding it to the smaller diameter in addition to extruding it into a backward spinning, smaller diameter flywheel.

The fluid drive coupling can never be 100 per cent efficient. Part of the momentum of the 1,000 rpm larger diameter flywheel has to be used to overcome the friction of the oil flow. The same holds true for the simple, three-element torque converter. Part of the momentum of the larger diameter 1,000 rpm flywheel (and a greater part is now needed) must be used to accomplish the conversion through the turbine. The result is that it is difficult to obtain, even with accurately designed blades, a 1,900 rpm backward spinning flywheel in place of the 2,000 rpm flywheel.

The same kind of flow losses exist in the stator. The best that could be done would be to design the exits of the stator blades to produce a 1,800 rpm flywheel rotating in a forward direction from the 1,900 rpm backward spinning flywheel. This would give the energy equivalent of a 900 rpm larger diameter flywheel. Even this 900 rpm fluid flywheel would not materialize in the larger diameter without some help from the pump. The pump blades can be slanted slightly backward, however, permitting the pump to run slightly faster (for example at 1,020 rpm) while the back bend of the blades aids the flow. This does not increase the torque on the pump, merely its speed. The pump senses a torque equal to the difference between the original 1,000 rpm flywheel and the 900 rpm flywheel equivalent of the small diameter flywheel entering the pump.

If the energy equivalents of the larger diameter flywheel are used, it can be said that the turbine has felt the turning force of the 1,000 rpm flywheel plus a 950 rpm flywheel, which is the equivalent of the small diameter 1,900 rpm backwardly rotating flywheel. This would give an index figure of 1,950 rpm as representing the turbine torque. The pump torque could be represented by a 100 rpm figure. The stator torque would be the equivalent of 1,850 rpm in the larger diameter flywheel—the equivalent sum of the 1,900 rpm and the 1,800 rpm small diameter flywheels.

It would be possible to make a torque converter where the relation of turbine torque to pump torque is 20 to 1 if the converter was designed for maximum flow efficiency at stall conditions when the turbine is standing still. If the turbine

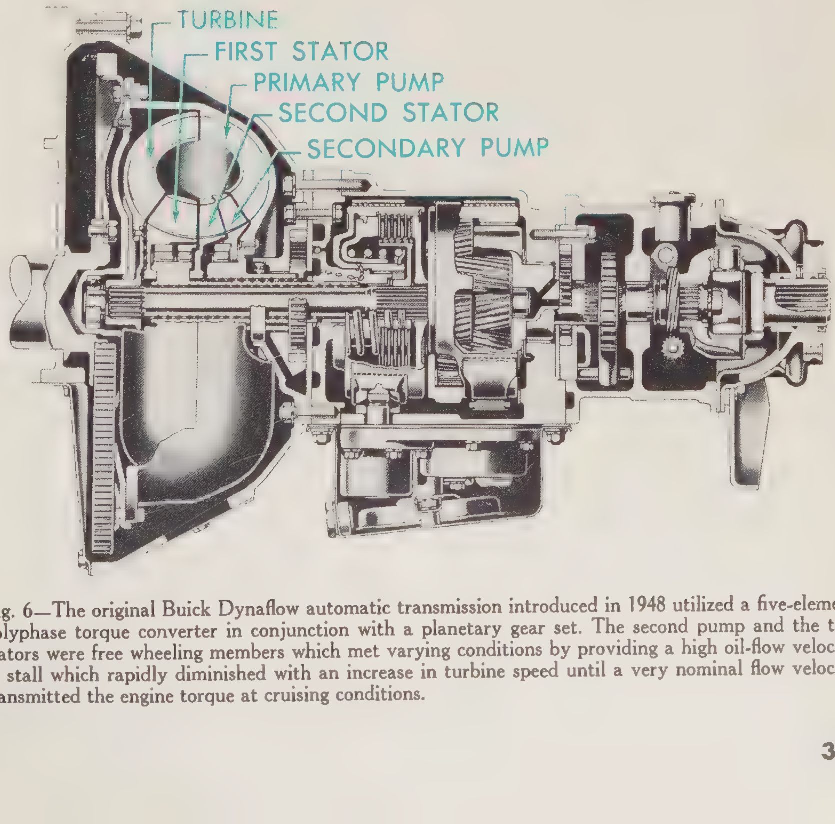


Fig. 6—The original Buick Dynaflow automatic transmission introduced in 1948 utilized a five-element polyphase torque converter in conjunction with a planetary gear set. The second pump and the two stators were free wheeling members which met varying conditions by providing a high oil-flow velocity at stall which rapidly diminished with an increase in turbine speed until a very nominal flow velocity transmitted the engine torque at cruising conditions.

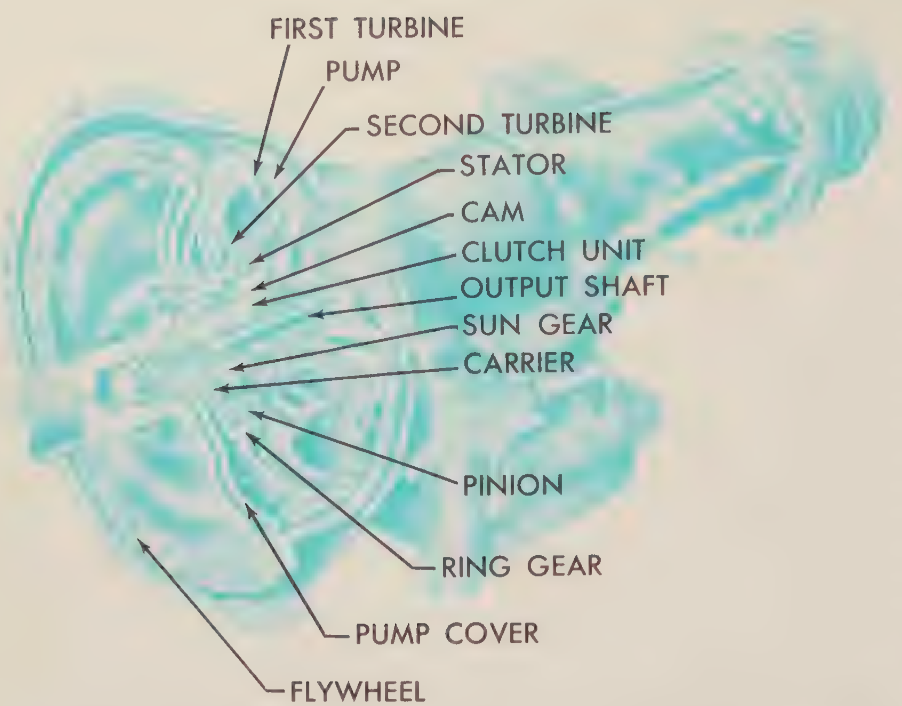


Fig. 7—The Buick Twin-Turbine Dynaflow automatic transmission utilized the torque-multiplying characteristics of a planetary gear set in conjunction with the torque-multiplying ability of a fluid torque converter. At low speeds all of the power was transferred through the first turbine and its planetary gear set. As vehicle speed increased, the torque on the first turbine decreased and the second turbine took over the drive at cruising speeds.

is standing still, however, it is doing no work and the overall efficiency is zero.

A practical torque converter must be designed with blade entrance angles that receive the flow properly at some useful drive ratio, for example a 2 to 1 torque multiplication. If the same conditions of flow velocity and efficiency are assumed as before, it is again necessary to assign a loss through the turbine which is the equivalent of 50 rpm in terms of the larger diameter flywheel and also an equal loss for the stator. From this it can be seen that by the time the oil re-enters the pump there is a total equivalent of 100 rpm lost out of the original 1,000 rpm flywheel's energy for hydraulic flow losses through the turbine and stator.

There also is the turbine's rotation to contend with. If there is a 10 per cent loss of energy due to hydraulic flow through the turbine and stator, it becomes obvious then that, if the turbine torque is to be twice the pump torque, the turbine speed must be 10 per cent less than one-half the pump speed. This sets the turbine speed at 450 rpm and requires that the turbine blades be properly formed to receive the 1,000 rpm flywheel of oil when the turbine is running at 450 rpm. To achieve this action the entrance and exit angles of the turbine blades must be accurately established for this condition.

The hydraulic loss assigned to the stator was the equivalent of 50 rpm of the 1,000 rpm initial flywheel energy, or five per cent. The rotational speed of the oil, therefore, before it enters the stator should be five per cent greater than when leaving the stator. The rpm of the oil entering the pump can be considered as an unknown quantity X and the rpm of the oil leaving the turbine as 105 per cent of X. The pump torque has been established as the difference in the flywheel values before and after passing through the pump, and the turbine torque is the sum of the fluid flywheel values before and after passing through the turbine. For 2 to 1 torque multiplication the turbine torque must be twice the pump torque. The following equation can be established and solved to determine the rpm of the oil entering the pump and leaving the turbine:

$$\begin{aligned} 2(1{,}000 - X/2) &= 1{,}000 + 1.05\,X/2 \\ X &= 656 \text{ rpm (oil entering pump)} \\ X(105 \text{ per cent}) &= 688 \text{ rpm (oil leaving turbine).} \end{aligned}$$

The turbine blade exit angles must be designed to produce a net backward spin to the oil of 688 rpm while the turbine has a forward speed of 450 rpm. This means that the turbine-blade exit angles must produce a fluid flywheel having a reverse spin of 1,138 rpm while the turbine is stationary, instead of the ideal stall-ratio torque converter's 1,900 rpm.

If a two per cent hydraulic loss is allowed for the pump member as before, along with providing a slight backward bend in the pump blades so that the initial 1,000 rpm energy flywheel leaves the pump rotating at 1,020 rpm, and if the entrance angle is set properly to receive 656 rpm oil from the stator, the basic design for the single-phase, three-element torque converter will be completed. The overall efficiency can be calculated by taking the pump speed times its torque and dividing by the turbine speed times its torque which gives an overall efficiency of 88 per cent. This is the so-called design point efficiency where ideal flow exists without entrance shock losses.

This single-phase, simple, three-element torque converter with stalled turbine cannot produce a 20 to 1 torque multiplication. It differs from an ideal torque converter designed for stall condition in two important respects. First, its members are not receiving oil properly when the turbine is stationary and large shock losses are encountered which increase the flow resistance. Second, its turbine and stator are not designed to accomplish the maximum possible turning of the oil as was done in the ideal stall-ratio torque converter. The turbine blades now produce a backspin of 1,138 rpm instead of 1,900 rpm, and the stator blades produce a forward spin of 656 rpm instead of 1,800 rpm. As a result, more oil must circulate through this milder path to produce the same forces in the turbine, and the pump must exert a greater torque on the oil because the stator no longer produces the maximum possible forward spin for the pump.

Both the shock losses and the simple circulation losses are proportional to the square of the flow velocity. This adds up to several times the losses in the ideal stall-ratio torque converter. Under the best of conditions it would be possible perhaps to obtain a 5 to 1 torque multiplication out of this single-phase converter at stall.

A similar situation exists at higher speed operation when the turbine runs

faster than 450 rpm, the design speed. All of the entrance angles would be wrong in the opposite direction, and the shock losses would rapidly decrease the efficiency. Torque converters of the single-phase design have this shortcoming. Their efficiency at the design point can be good, and their torque multiplication at stall can be adequate. However, their efficiency at higher speed operation suffers so much that the single-phase design is not useable.

What the torque converter needs is a constantly changing blade entrance angle for its members so that they can accommodate themselves to the ever changing conditions of turbine speed. This presents quite a complex design problem for which there seems to be no apparent solution. A part of the solution, however, can be obtained by permitting the stator member to free wheel when the direction of oil flow has changed sufficiently to actually exert a forward rather than a backward reaction on the stator. If the stator free wheels at this point, there will be no additional shock losses.

A second way to obtain part of the solution, and one which has now been made practical in the Buick Variable-Pitch Dynaflow, is to change the angle of the stator blades to better satisfy varying car speed conditions.

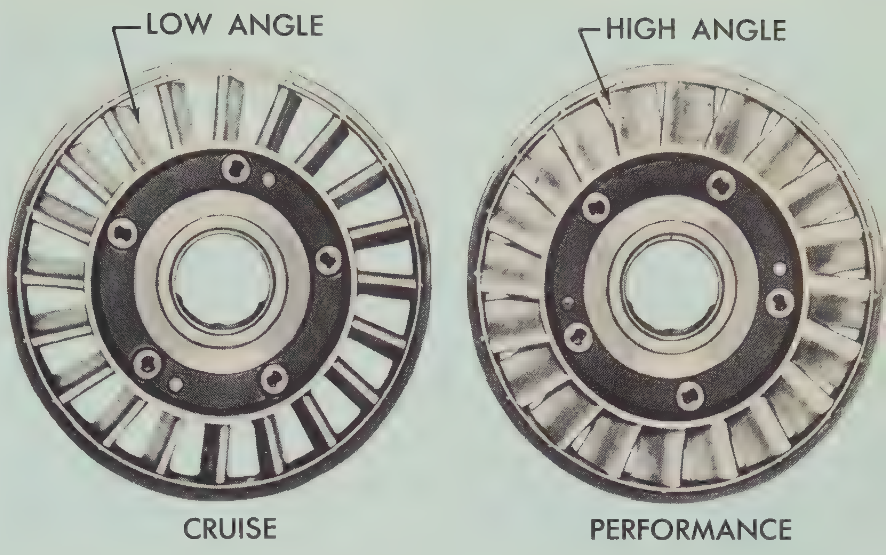


Fig. 8—The Buick variable pitch Dynaflow, introduced in 1954, retained the features of the twin-turbine Dynaflow but also added a stator having variable or controllable pitch blades. The 20 blades were mounted on individual crank pins so that the pitch could be changed approximately 75°. The stator blades were actuated by a stator piston linked to the throttle linkage through a control valve. Oil pressure, created by throttle movement, moved the stator piston and the blades to low angle for cruising conditions or high angle for high performance conditions.

Buick Dynaflow Automatic Transmission

The Buick Dynaflow torque converter automatic transmission is an example of progress made in the application of hydro-dynamic drive. The original Dynaflow was introduced in 1948. The design, which adapted a basic torque converter into a five-element polyphase converter, consisted of a primary pump, a secondary pump mounted on a free wheeling clutch, a turbine, and two stators also mounted on free wheeling clutches (Fig. 6). The free wheeling members met the varying conditions by providing a high oil-flow velocity at stall which rapidly diminished with increased turbine speed until a very nominal flow velocity transmitted the engine torque at cruising conditions.

In 1952 Buick introduced the Twin-Turbine Dynaflow which greatly improved acceleration and torque converter efficiency and reduced the engine speed for a given car speed. This design consisted of a pump, a first and second turbine, and a free wheeling stator (Fig. 7). The first turbine was connected to the converter's output shaft through a torque-multiplying planetary gear set. The second turbine was directly connected to the converter's output shaft. At low speeds, when top performance is required, all of the power was transferred through the first turbine and its planetary gear set. As vehicle speed increased, the torque gradually and smoothly diminished on the first turbine and increased on the second turbine until it completely took over the drive at cruising speeds. Meanwhile, the first turbine was rotating freely whereby it could re-enter the drive whenever its high torque-producing ability was required.

In 1954 Buick introduced Variable-Pitch Dynaflow. This design retained the twin-turbine feature but also added a stator having variable or controllable pitch blades (Fig. 8). The automatic control of the stator-blade pitch provided the best angle for cruising and economy driving, as well as the best angle for performance and fast acceleration. With the fixed stator-blade angle of the previous Twin-Turbine Dynaflow design a compromise angle which would give the best results for both conditions had to be used.

In 1955 Buick introduced a still further step in automatic transmission design improvement. This new design contains an additional fixed-blade stator located between the first and second turbines. This additional double regenerative stator provides additional performance at lower speed where it is most needed.

Developmental steps of the type described here have constantly improved the Buick Dynaflow transmission and reflect the ability of the basic torque converter, when properly and uniquely adapted, to provide absolutely smooth, fast responding, automatic drive without the need of shifting gears.

Conclusion

The ultimate in automatic drive has not been reached, and activity in this field of automotive engineering continues. The results obtained thus far in the development of automatic transmissions, however, have proven to be highly successful, and the percentage of cars equipped with automatic drive has steadily increased. In 1955 alone over 65 per cent of all passenger cars manufactured were equipped with automatic drive.

What the future will bring will depend on the abilities of engineers to develop new or better ways for providing automatic power transmission from the engine to the driving wheels.

A Product Engineering Study:

Design of an Axial-Type Refrigeration Compressor

During the past several years there has been increasing emphasis placed on the importance of design and designers in industry. Unfortunately, many young engineers entering industry have avoided careers in design, fearing that the field might limit them in the way of technical expression. This paper not only discusses the design aspects of an axial compressor, but also points out how the designer calls upon specialists in the fields of research, testing, and manufacturing, and welds their contributions into the design of a commercial product. Before any new product can be designed, it is necessary to set up certain goals which the design is to fulfill. If the new product is similar to one already in use, these "ground rules," as they might be called, can be the result of field experience on the old product. However, if, as was the case with the axial compressor discussed in this paper, there was no previous field experience, then it may be necessary to conduct preliminary tests to determine what the design objectives should be.

In September 1951 the Power Development Section of GM's Engineering Staff was given the assignment of reviewing the various types of compressors used for refrigeration. In addition, this group was to design an entirely new compressor for an automobile air conditioning unit which would as nearly as possible fulfill all the requirements demanded of an ideal unit.

Design Criteria

Some preliminary test work had been done. These tests indicated that a cooling capacity of about 12,000 Btu-hr at 25 mph would be satisfactory. At the outset of the program several characteristics of the ideal compressor for automotive use were set up as follows:

- Minimum size
- Minimum weight
- Low cost
- Life expectancy consistent with normal automotive practice
- Freedom from vibration
- Capable of operation at high speed
- Low noise level
- High efficiency
- Large capacity.

It is difficult to arrange such a grouping in order of importance, and the above list does not even attempt to do so. In any event, it is only by sound engineering that the best compromise of all features and, consequently, the best designed unit is made.

Many different types of compressors were considered and analyzed for their desirable characteristics. The field narrowed down to four types: Vane type, two-cylinder and four-cylinder crankshaft-type with reciprocating pistons, and a wobble-plate type with reciprocating pistons. In order to evaluate the various types, units were tested on a calorimeter. From these tests it was possible to make a "designer's estimate" of the four units. In the rating four points represent the best unit, while one point denotes the worst (Table I). Some of the compressors have the same rating on some items, meaning that they were approximately equal. From these ratings it was evident that the wobble plate excels in all but two respects—noise level and capability to operate at high speeds. In both of these cases it is only slightly inferior to the vane type. Thus, it appeared that the wobble plate unit was best suited to the needs of the proposed air conditioning unit, and work was started on a proposed design.

The first questions to settle were the refrigerant to be used, the displacement of the unit, and the number of cylinders. Freon-12, developed by General Motors several years ago, seemed the logical choice for the refrigerant due to its moderate pressures, good refrigerating effect, and non-toxicity. Knowing the desired capacity, the thermodynamic characteristics of Freon, the desired compressor-to-engine speed ratio, and the volumetric efficiency of the compressor, it was a

ESTIMATE OF DESIGN FACTORS

	VANE	2-CYL. RECIP.	4-CYL. RECIP.	WOBBLE PLATE
Minimum Size	2	3	1	4
Minimum Weight	1	3	2	4
Minimum Cost	1	3	2	4
Adequate Life	3	4	4	4
Freedom from Vibration	3	1	4	4
Capable of Operation at High Speed	4	3	3	3
Low Noise Level	4	2	3	3
High Efficiency	2	3	3	4
	20	22	22	30

TABLE I—In many instances, when working on new designs, it is helpful to prepare a "designer's estimate" of various factors. In order for such an estimate to be of value, the designer must analyse the items involved with an open mind and weigh certain items in light of his previous experience and background. Four points represents the best unit, while one is the worst.

By JOHN DOLZA,
WILLIAM K. STEINHAGEN,
and PHILIP L. FRANCIS
General Motors
Engineering Staff

Design engineering—

a challenge to the

young engineer

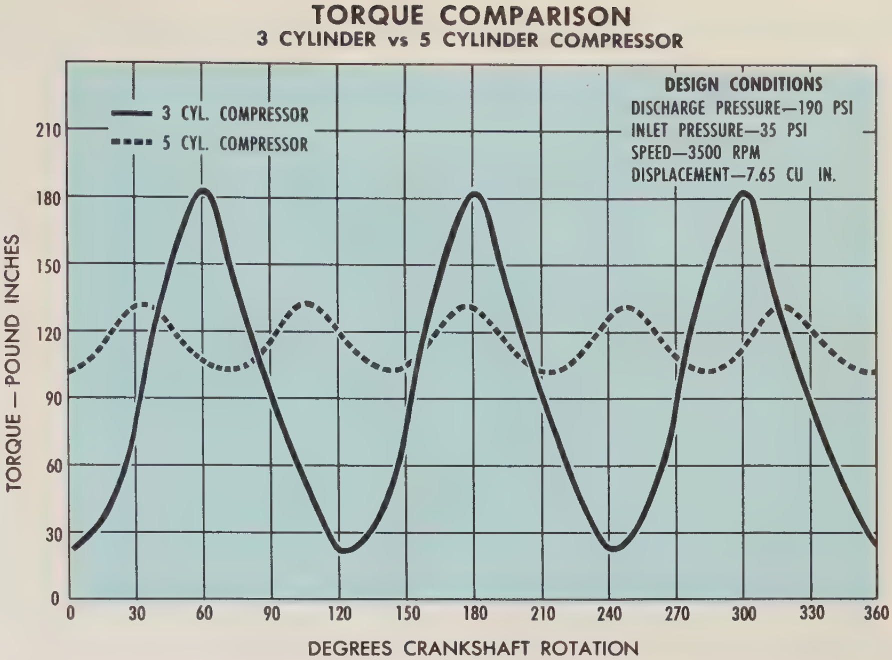


Fig. 1—The torque curves of a three-cylinder and a five-cylinder compressor of the same total displacement (7.65 cu in.) shows the more uniform torque of the five-cylinder type. Since the torque is influenced by such things as bore, stroke, and weight of the parts, it is necessary to make preliminary layouts to determine these items before the calculations can be made.

simple matter to calculate the required displacement—7.65 cu. in. per revolution.

In order to design a low cost device it was desirable to have as few parts as possible. When selecting the number of cylinders required, it was also necessary to consider such items as balance, torque characteristics, and overall size. A minimum of three cylinders was needed in order to achieve complete primary balance in a wobble-plate mechanism.

An analysis of the torque fluctuations of a three-cylinder arrangement showed peaks which would create severe problems in clutch design and belt life, as well as impose very high loads on the torque restraining member of the wobble plate. A four-cylinder unit would be much better from a torque standpoint. For an axial compressor, however, an even number of cylinders cannot be arranged as compactly as can an odd number. A five-cylinder unit seemed the best compromise from all standpoints and for this reason was selected. A comparison of the torque curves of the three- and five-cylinder units showed the five-cylinder unit to be better (Fig. 1).

The selection of a 1¼-in. diameter bore and 1¼-in. stroke represents a compromise between the desire for low inertia forces which result from a large-bore, short-stroke unit and low re-expansion losses which result from a small-bore, long-stroke unit.

Structural Details and Testing of First Design

When the bore and stroke were selected, the basic layout was started. As the design progressed it was necessary to calculate bearing loads, stresses, port areas, and gas velocities. Since all the various parts are interrelated in their action upon one another, it is constantly necessary to revise, recalculate, and revise again to achieve the best combination possible.

The first experimental unit had a cast iron crankcase, cylinder block, valve plate, head, and seal housing (Fig. 2). The inlet to the cylinders was through a rotary inlet valve driven by the crankshaft and timed to open 28° after top-dead-center (this allowed for re-expansion of the gases trapped in the clearance

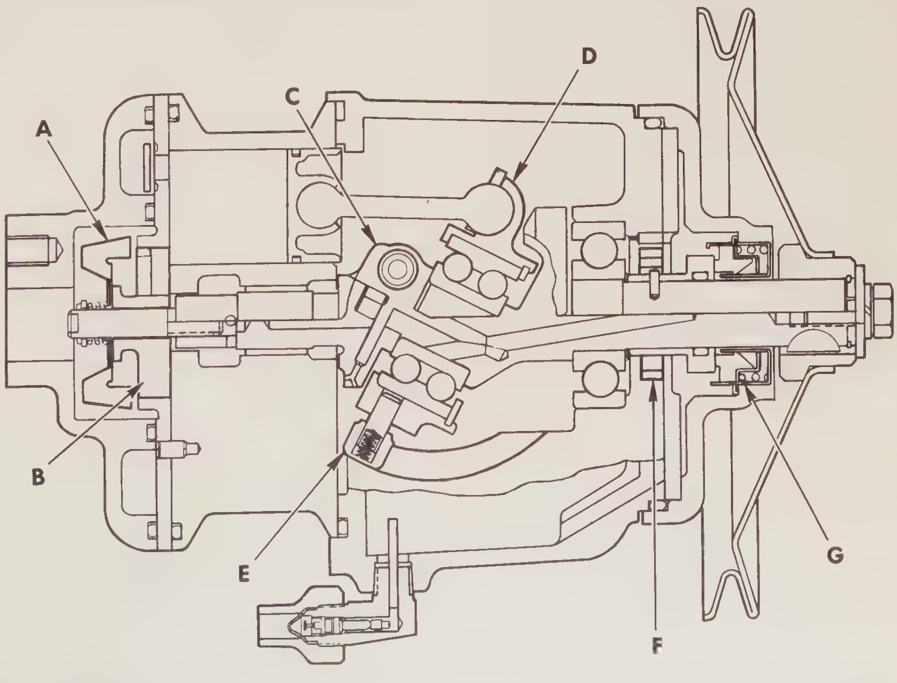


Fig. 2—The main features of the 7.65 cu in. compressor included a centrifugal oil separator *A*, rotary intake valve *B*, two-piece shaft *C*, wobble plate *D*, guide shoe *E*, oil pump *F*, and shaft seal *G*. The unit without clutch weighed 32 lb.

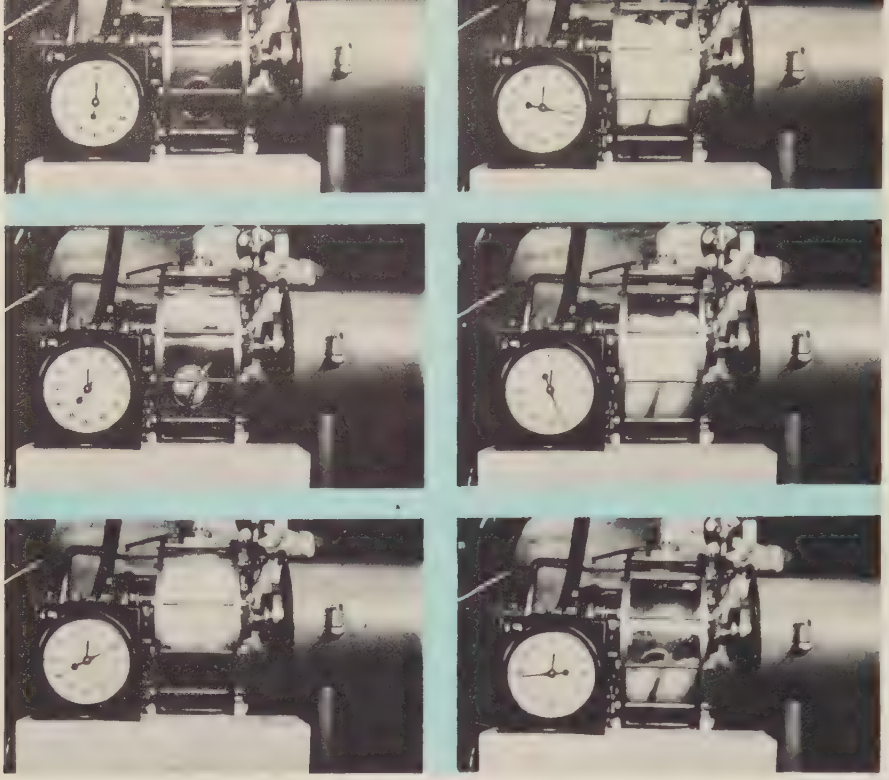


Fig. 3—This series of photographs of a specially constructed compressor with a plastic sump shows the oil foaming problem faced by refrigeration compressor designers. In this test the compressor was allowed to stand for a period of time until the refrigerant had condensed into the sump (typical of a unit standing overnight) after which the unit was started and accelerated to 3,500 rpm as rapidly as possible. As the pressure in the sump is reduced by the compressor, the Freon-12 boils rapidly, leaving the crankcase and carrying a large amount of oil with it.

space), and to close shortly after bottom-dead-center. Discharge was through individual exhaust valves of the automatic reed type. The piston was made of steel and had two piston rings, one for sealing and one for oil control. A ball-joint connecting rod of carburized and hardened steel was fastened to the piston by swaging and to the wobble plate by means of a retainer and rivets. The wobble plate was supported on the shaft by means of a double-row ball bearing and was prevented from rotating by the use of a pin and shoe operating in a guide in the crankcase. The crankshaft was made in two pieces, fastened together with a special pinch bolt, and supported in a single-row ball bearing at the front and in a plain bronze bushing at the rear. Forward of the front main bearing was a gear-type oil pump which provided lubrication for the shaft seal, as well as all the moving parts. The crankshaft was drilled to provide an oil passage to the rear main bearing. The shaft seal was of conventional type, utilizing a carbon-disc sealing against a cast iron ring.

Due to the solubility of Freon-12 in lubricating oil, oil separation, especially during starting, is a problem faced by all compressor designers. The extreme boiling caused by the sudden reduction in crankcase pressure in some cases can cause the oil to foam out of the sump (Fig. 3). Pictures of a specially constructed compressor which had a plastic oil sump show violent foaming and the

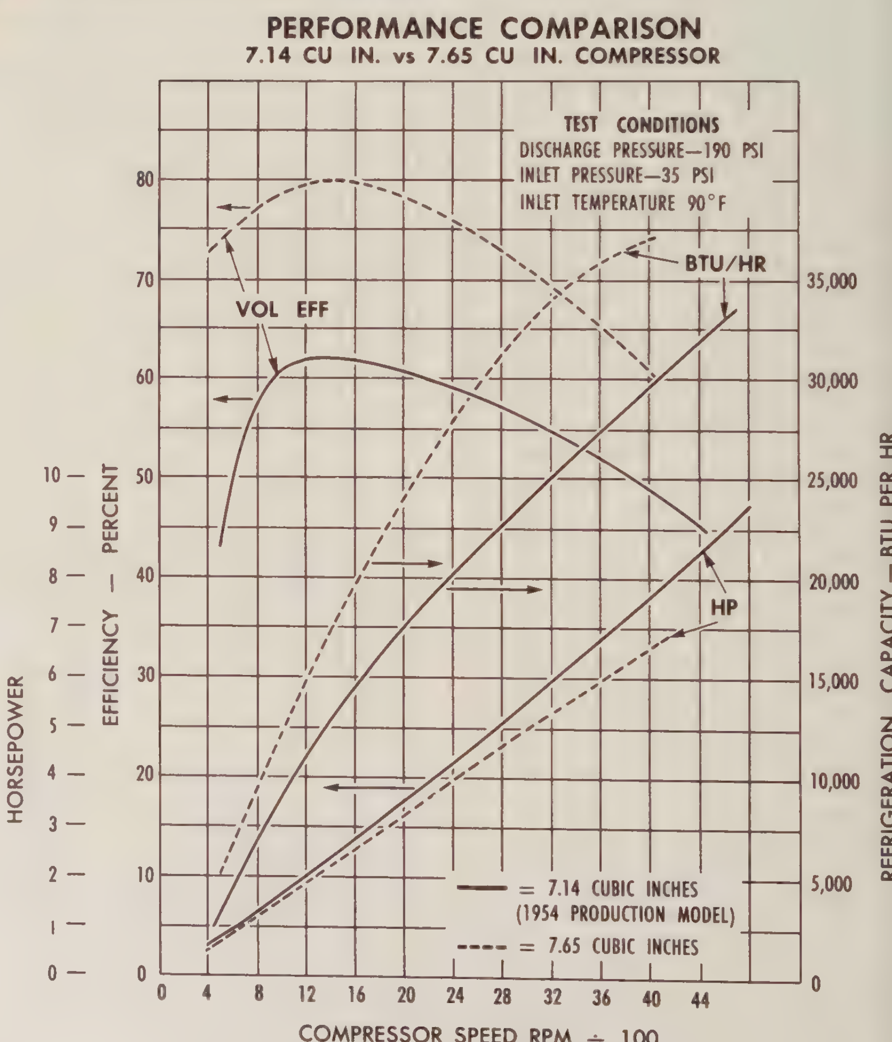


Fig. 4 (right)—Information obtained from calorimeter tests is used to plot various compressor characteristics, such as volumetric efficiency, refrigeration capacity, power consumption, and adiabatic efficiency. From these curves it is possible to compare compressors, regardless of displacement, to determine what unit has the best performance. In the curve shown it can be seen that the 7.65 cu in. compressor has much greater volumetric efficiency and, consequently, much greater refrigeration capacity. However, due to the reduction in friction and pumping losses, it has a lower power consumption than the 1954 production compressor.

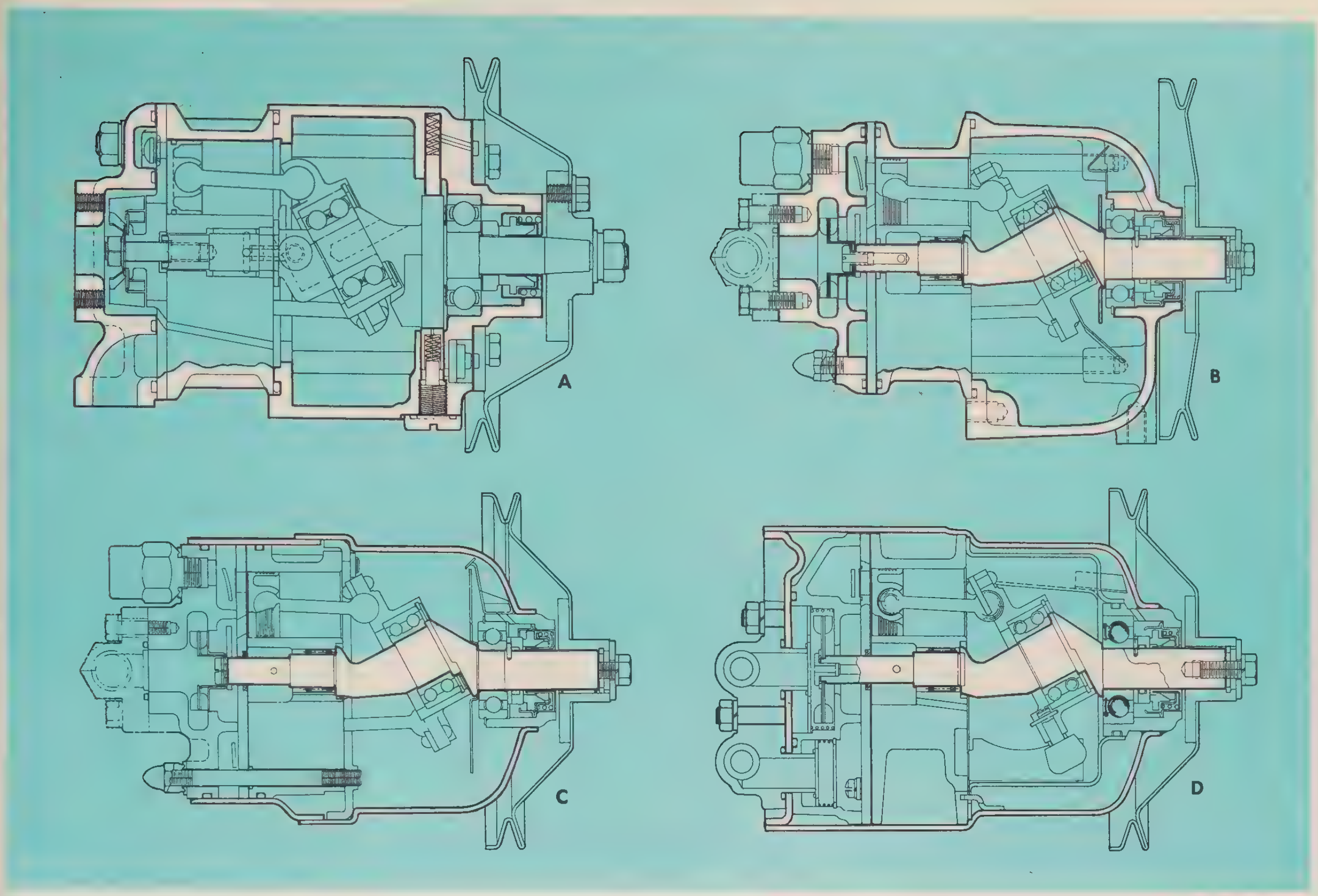


Fig. 5—In order to improve the compressor many design studies were made, four of which are shown above. At *A* the unit has been enlarged to 9.28 cu in., but is basically the same construction as used previously with the exception of the oil pump which has been changed from gears to a plunger type. The next stage *B* in the design retained the cast crankcase construction, but the shaft is one piece, the rotary intake valve has been replaced by automatic reeds, and the oil pump has been eliminated in favor of a splash system. The first attempt at the use of a stamped crankcase is shown at *C*, while a further attempt is shown at *D*. It should be kept in mind that these studies were made on paper only and that none of them was ever actually built. The features, however, were tested by converting 7.65 cu in. units.

carry-over of oil from the sump, up the crankcase vent, to the inlet side of the compressor. To return this oil to the crankcase a centrifugal-type oil separator was used in the inlet chamber. This type of separator, driven by the crankshaft, causes oil carried into the inlet cavity to be centrifuged into a pocket from which it is drained back to the crankcase. The separator functioned well by keeping oil circulation low.

After some developmental work on the rotary intake valve to determine the proper clearance and timing, performance was rated as satisfactory (Fig. 4).

Field Tests Provide Basis for Second Design

At this point in the program the Engineering Department of Frigidaire Division was asked to cooperate in the building of compressors for field tests and to conduct the tests of the wobble-plate compressors in comparison with the rotary compressors which were being produced at that time. Field reports indicated that the original capacity figure of 12,000 Btu-hr at 25 mph was not high enough and should be increased to 15,000 Btu-hr. Due to the increased capacity and the fact that further design and manufacturing studies indicated possibilities for further cost reduction, it was decided to redesign the unit completely. Displacement was increased from 7.65 cu in. to 9.28 cu in. per revolution, and the bore and stroke were changed to $1\frac{3}{8}$ in. by $1\frac{1}{4}$ in. A number of designs were suggested on paper which included changes in the lubrication system, crankshaft construction, piston design, and intake valve design (Fig. 5). These designs also detailed means for attaching the piston rod to the wobble plate and replacing the cast iron crankcase with one of stamped sheet metal construction. All of these studies were directed toward developing a lighter, more compact, and lower cost unit.

While the design studies were progressing, test work was being done on the original 7.65 cu in. unit. These tests were aimed at providing information to aid in developing the new design. For example, indicator card studies were made to help determine bearing loads. These studies were made by means of condensor-type and catenary diaphragm strain gage-type pressure pick-ups similar to those used in engine tests (Fig. 6). From these studies it was apparent that the discharge port was too small, resulting in peak pressures in excess of the design values. By increasing the port diameter from 0.281 in. to 0.391 in., the peak pressures were reduced by 10 per cent, while the power lost during the discharge stroke was decreased 35 per cent. Similar work was done on the intake ports to determine the optimum size.

The test work done on 7.65 cu in. units was also of great value in redesigning the one-piece crankshaft. A double-row ball

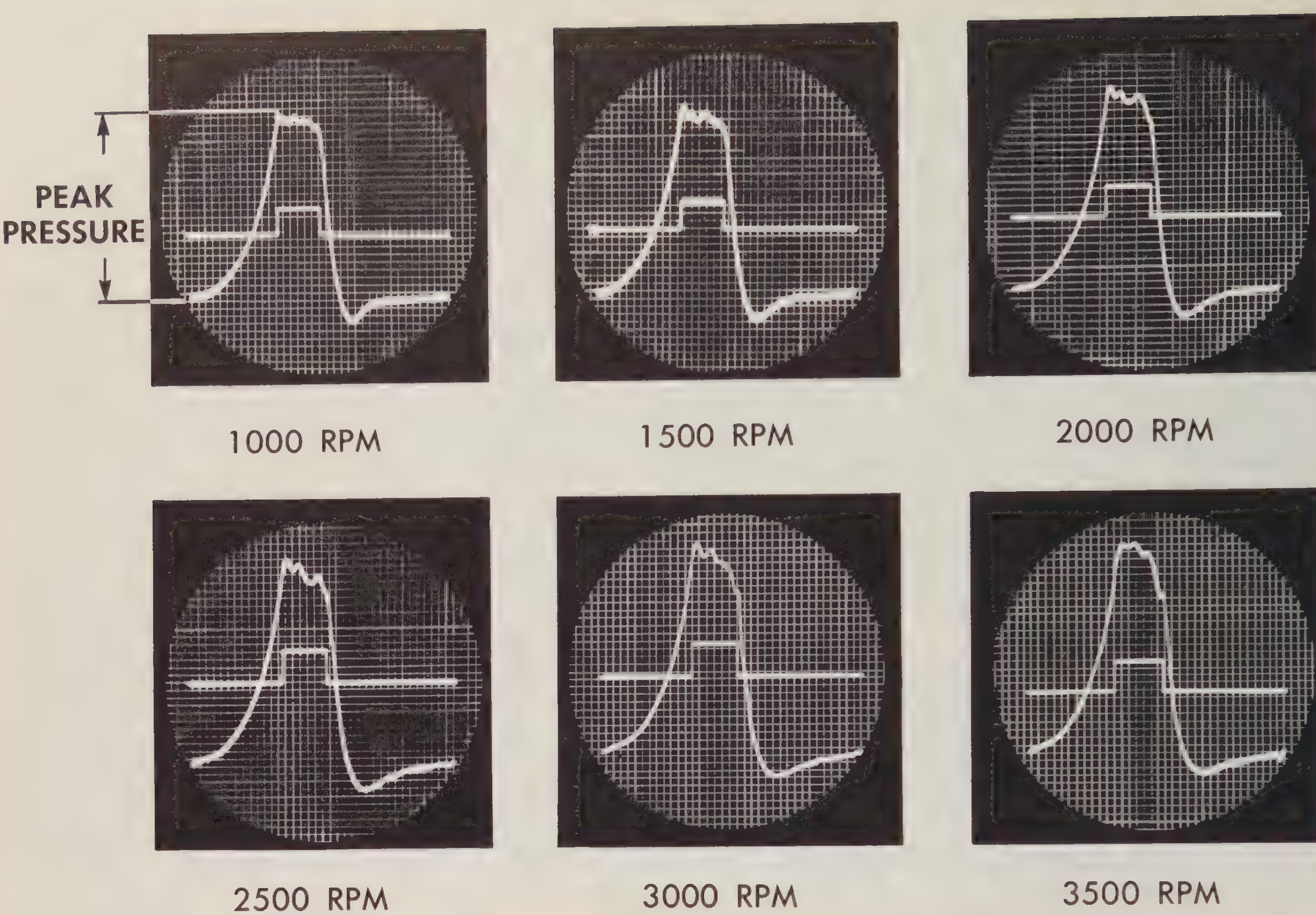


Fig. 6—Pressure-time traces, such as these, were obtained on the 7.65-cu in. compressor. From these oscilloscope records it is possible to construct an indicator card diagram and determine such items as peak pressure in the cylinder, suction work, discharge work, and mechanical efficiency. Note how the peak pressure increases with speed. The broken horizontal trace indicates opening and closing of the discharge valve.

Fig. 7—The final intake reed valve design (right) was evolved on the basis of having all five valves parallel to the rolling marks of the Swedish steel used. That this is necessary can be seen from *A* (left) where the valve failed after a very short period of operation. This part is deceptively simple in appearance. In reality it is a very highly stressed piece, subjected to many hundred million cycles during its life. Such a part requires the best materials, and great care in both design and manufacture to avoid any stress concentrations which will shorten its life.

bearing, which could be assembled over a one-piece shaft, was developed in cooperation with New Departure Division. This development resulted in a shaft design which was more economical to manufacture and which simplified assembly by eliminating the problem of aligning the bearing journals. A shaft of the new design was made and tested in a 7.65-cu in. unit. By running dynamic crankshaft bending tests, it was found that resonant vibration occurred within the operating speed range of the compressor. Thus, the one-piece shaft for the 9.28-cu in. unit was designed to avoid such a resonant condition.

The inlet reed valve also was developed on the 7.65-cu in. unit. The first design had valves which were not parallel to the rolling marks of the metal (Fig. 7, left). Stress concentrations about the rolling marks caused failure of the valve at the base of the reed. Since cross-rolled stock, which might have eliminated this trouble, is expensive, the design was based on having all inlet reeds parallel to the rolling marks. This placed severe limitations on the design, however, as locations

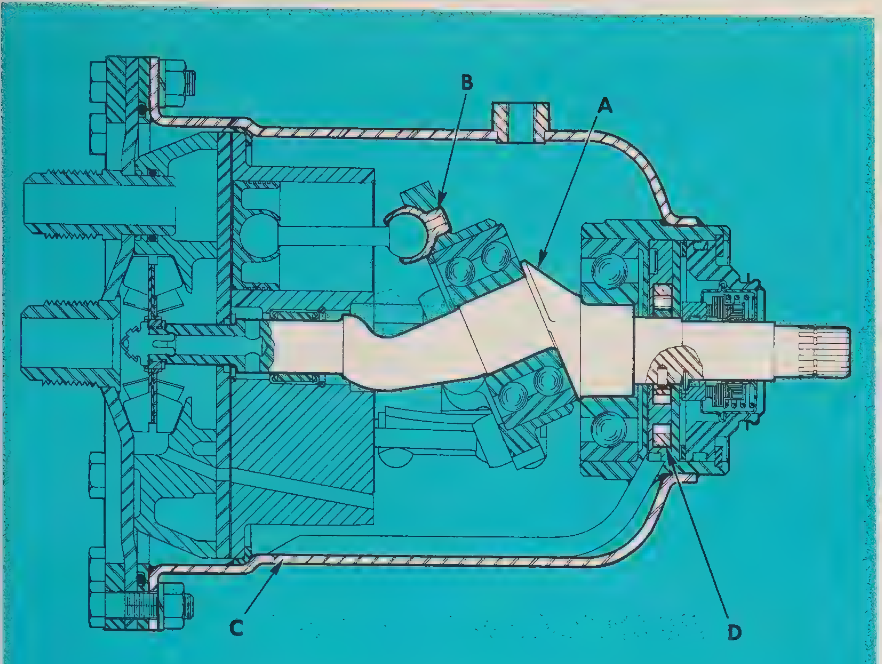


Fig. 8—The first model of the 9.28-cu in. compressor contained many components that had been developed on the 7.65-cu in. unit. These included the one-piece shaft *A*, a new method of retaining the piston rod to the socket plate *B*, and the sheet metal construction *C*. An oil pump *D* was used, as the developmental work on a splash system did not prove satisfactory.

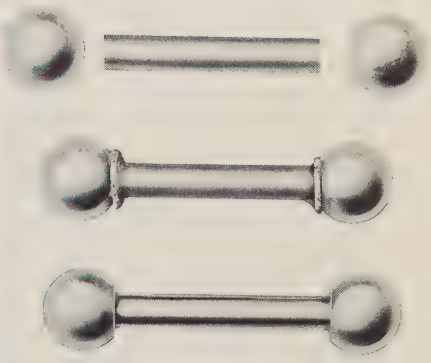


Fig. 10—Due to the necessity for extremely round, hard balls on each end of the connecting rod, it was necessary to develop a new method of manufacture. The manufacturing tolerance on sphericity of 0.0001 total indicator reading is maintained by welding ball bearing balls to a soft steel rod and grinding off the flash formed at the weld. This resulted in a much less expensive part with improved functional qualities.

of the valves were then fixed. It required considerable ingenuity on the part of the designer to fulfill this requirement and, at the same time, keep the unit as compact as possible. The final inlet valve design (Fig. 7, right) proved equal to the rotary valve in performance, yet cheaper to manufacture and less sensitive to dirt or other foreign materials.

The first prototype of the 9.28-cu in. compressor performed exceedingly well (Fig. 8). While working with the New Departure engineers, it was realized that the unit could be made still simpler if a special ball bearing were available having its shaft bore at an angle. Design of such a bearing permitted the use of a straight shaft, yet gave the required angle to the wobble plate (Fig. 9). Subsequent tests showed no loss in performance, and the result was a much simpler unit.

As occurs many times in the design of a new product, certain items which are necessary from a functional aspect turn out to be rather expensive to manufacture. It is necessary for the designer then to re-examine those items to try and use less expensive construction, while keeping the required functional properties.

The ball-ended connecting rod turned out to be one of these items. In order to have low noise level and long life it was found essential to have the ends of the connecting rod extremely round. The manufacturing tolerance on the balls called for spherocity within 0.0001 in. Manufacture of the rod by conventional means, (rough machine, carburize, harden, crush grind, and lap), proved costly. Working with the engineers of the Process Development Section, it was found possible to take hardened steel

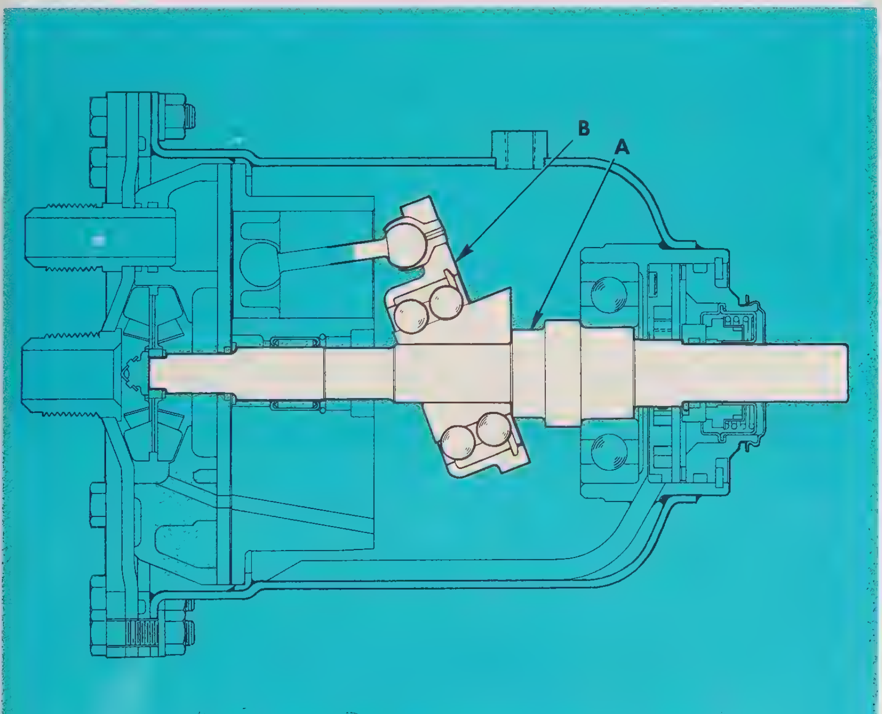


Fig. 9—The modified version of the 9.28-cu in. unit, in which a straight shaft *A* and special ball bearing *B* were used to impart the wobbling motion to the wobble plate, is shown here.

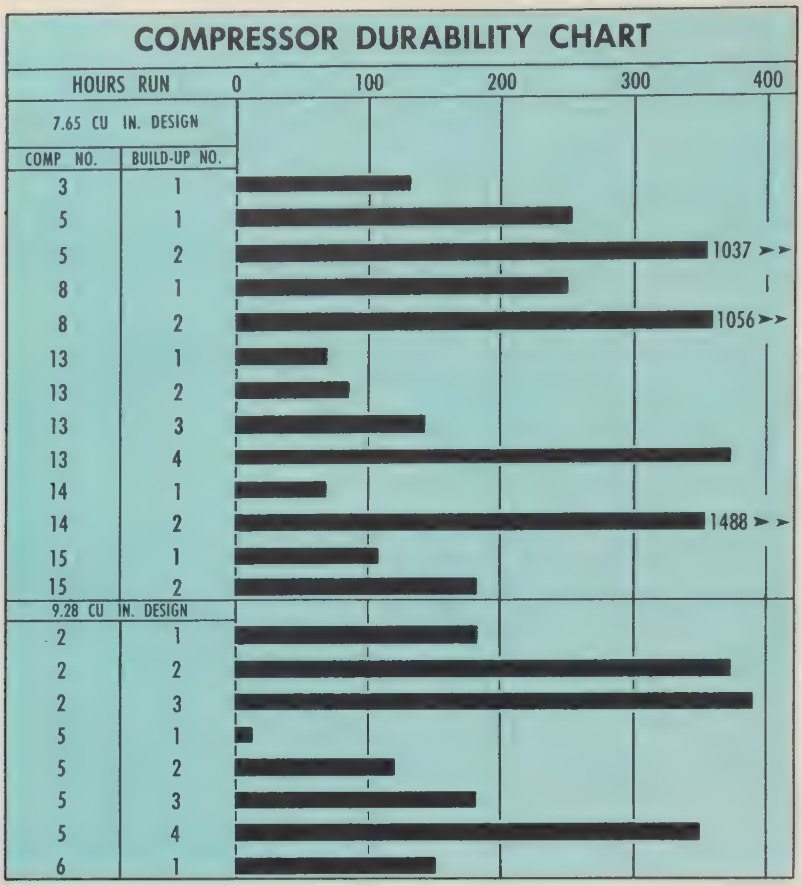


Fig. 11—A typical compressor durability chart is reproduced here. The failures shown do not mean that the complete unit failed, but only that some particular part failed. In many instances it was possible to change only a few parts and put the compressor on life test again. (Each time a compressor part is replaced or modified a new build-up number is assigned to the unit.) Thus, some parts accumulate much more time than others, however, it is the items which fail early that receive intensive attention to remedy the design or manufacturing faults.

balls, similar to ball bearing balls, and weld these to a low carbon rod without distorting the ball (Fig. 10). Such a technique, which was readily adaptable to automatic equipment, resulted in a part which was not only considerably less expensive but had improved functional properties. The surface finish, spherocity, and strength were all superior to the machined rod. Tensile impact strength, for example, was increased from 35 ft-lb to 90 ft-lb.

COMPARISON OF 1954 AND 1955 PRODUCTION UNITS

	1954 ROTARY	1955 AXIAL
Displacement, cu in. per rev.	7.14	9.28
Weight (including clutch), lb	60.8	38.8
Peak Volumetric Efficiency	65%	79%
Peak Adiabatic Efficiency	45%	74%
Capacity at 1,000 rpm, Btu-hr	4,500	14,500
Horsepower at 1,000 rpm	1.75	1.65

TABLE II—A final comparison of the 1954 production unit with the 1955 production unit shows how well the design objectives have been achieved. It is interesting to note that while the capacity was increased 325 per cent, the power required was reduced by 6 per cent.

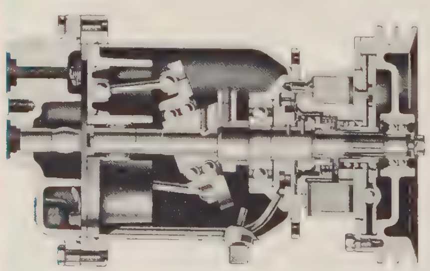


Fig. 12—The production unit contained most of the basic elements proved by previous designs plus many items added by Frigidaire Division engineers to improve the performance or simplify manufacture. The combined efforts of many people, including engineers, designers, metallurgists, production specialists, and others, resulted in the production of a light, compact, and highly efficient compressor unit.

Endurance Tests Indicate Service Life

No design, regardless of its simplicity or efficiency, is of commercial value unless it has an adequate service life. For this reason endurance tests were run in the laboratory concurrent with the design and development phases of the compressor. As various components were proved satisfactory from a design and performance standpoint, they were placed on life test, first in 7.65-cu in. units, and later in 9.28-cu in. units (Fig. 11). With the cooperation of engineers in GM's car Divisions a standard life test of 350 hours at maximum speed, 17.5 hours at 10 per cent over speed, and 24 hours under extremely high head pressure at idle speed was agreed upon. While 350 hours may seem rather short, it is equivalent to driving a car at 100 mph for 35,000 miles with the air conditioner operating continuously at maximum capacity—a service life which is more than adequate on a car in normal use.

After this design was proved satisfactory with respect to capacity, service life, performance, and manufacturing cost, work was started with Frigidaire Division to release the unit for production. The Frigidaire Engineering Department made some design changes to incorporate a magnetic clutch and other items which their tests indicated would improve the unit (Fig. 12). Mounting arrangements were designed so as to permit the same basic unit to be used on all five makes of General Motors cars.

Before production actually was started in September 1954, some 300 experimental or "pilot" models had been built and tested, both in the laboratory and on road test cars. Over 50,000 endurance hours were logged before the unit was deemed a proven device.

Summary

This discussion of the development of an axial compressor may be of some help in gaining a better understanding and appreciation of design engineering. The project engineer and designer, working as a team, have applied the fundamentals of science and engineering, as well as creative ingenuity, to produce a device which is a good compromise of all the design criteria originally set up. That the unit can be improved still further is evidenced by new designs now on the drafting board aimed at simplifying manufacture, improving performance, and reducing size and weight (Table II).

Some Observations from Working With Two Generations of General Motors Inventors

By GEORGE H. WILLITS
Patent Section
GM Engineering Staff

Invention begets invention, and inventors also lead others to become inventive

CHARLES F. KETTERING, consultant to the Research Staff and a Director of General Motors, believes that men can be taught to invent. He often tells of getting his scientists and engineers together and asking them how they would solve a particular problem if they could no longer solve it the way they had always done. This is precisely the problem that faces a business whose competitor has patented what seems to be the only practical and desirable way of making an essential improvement which has rendered previous designs obsolete. This was the kind of challenge which the indomitable, late Thomas Alva Edison dearly loved. The challenge to invent produced by the patent laws has probably made successful inventors of more people than the inducement of the patent grant itself. Faced with the stern choice "invent or get out of business," the imaginative man of the lagging enterprise invents and soon finds that there are other and much better ways of doing almost everything.

In observing two generations of General Motors inventors at work one observation stands paramount: for every product, process, or method "there must be a better way." GM President Harlow H. Curtice, whose early training was in accounting and finance, in a recent statement attributed the success of the organization to "the inquiring mind." The provisions of the patent law have created an arbitrary distinction between inventors and others who possess the inquiring mind. With the object of promoting progress of science and the useful arts, the patent law offers a 17-year exclusive right of use to those who devise new and useful improvement in products and machines or processes for making them. These constitute but a small part of the tremendous field within which men with the inquiring mind operate and in which they frequently display as great ingenuity and persistence in solving problems as they do in the statutory field of invention.

Perhaps the most exemplary inquiring mind in General Motors in the field of invention is Charles F. Kettering, who is known by all of his co-workers and friends as "Boss Ket."

The son of a farmer, he worked his way through school in the tradition then exclusively American. In other countries class rigidities required that the workman's son must not aspire to be educated but must remain a workman or, if he preferred, apprentice himself to a trade. After teaching school and being a telephone repairman, Mr. Kettering finally completed his electrical engineering degree work in 1904 at The Ohio State University at the age of 28, five years behind his more fortunate classmates. A period then followed in which he engaged in varied developmental activities in Dayton, Ohio, resulting in numerous inventions.

One Inventor Stimulates Another Inventor

In 1920 Mr. Kettering became head of GM's research laboratories (now known as the Research Staff) at a time when only a half-dozen industrial organizations were willing to sponsor such an activity. This appointment marked a turning point in Mr. Kettering's attitude toward invention. Before, there had been a flood of patents in his own name. Now he seemed to recognize that as head of the laboratories his job was to stimulate invention by his staff and that, by doing so, he could multiply many times his effectiveness in the field of invention. His name appears less frequently on patents after 1920. He encouraged his men to take out patents, even though sometimes the ideas seemed of little worth; he believes it is good for all men to project their thinking into the future even though their power of penetration may be very small. He taught his men not to be afraid of failure or the ridicule of new ideas by the great majority of us who cannot see much beyond today. Once but an inventor, he became a creator and leader of inventors.

A striking episode in the midst of the depression was the Diesel engine development to which Mr. Kettering gave impetus even though other businessmen advised GM that the Diesel engine would never find applications in railroading.

When GM management was considering how to assemble a team for this development, Mr. Kettering suggested bringing together a capable group of men who knew nothing about Diesels—rather than employing experts from abroad. His suggestion was adopted, and, inspired by him, his newly organized group of engineers worked without regard to office hours designing and redesigning and solving difficult problems. They converted his personal yacht into a sea-going engine test cell circling in the waters of Lake St. Clair evening after evening and weekend after weekend to prove new features of design. They learned how to manufacture fuel injectors in quantity with finer tolerances than had ever been done before. The leaders in this engineering group went on to attain positions of importance in the businesses which they had built up by their labors.

Thus, instead of failure, the Diesel engine became a financial salvation for the railroads and opened up new power applications in many fields. As a result of this job-creating development, there are now three Divisions of General Motors whose people are engaged in the manufacture of Diesel engines and components and still another Division where Diesel locomotives are made.

Like Mr. Kettering, there have been other men in General Motors whose independent, inventive minds have had the freedom to develop their ideas into reality. Also like "Boss Ket," many of them learned how to encourage others to

free themselves of fear of criticism and failure and to boldly invent and promote their inventions. Some worked directly for Mr. Kettering. Others are located in various Divisions of General Motors and in other Central Office Staffs. To attempt to mention the many individuals and their accomplishments is beyond the scope of this discussion. A few names can be cited, however, not to imply that those excluded made lesser contributions, but rather to point out some specific examples of the type of inventor in General Motors who has made significant contributions himself and who also has led and inspired others in creative work. The examples given are confined to groups now at the Technical Center because this paper is a contribution to a commemoration of its opening. They are restricted to the older of these groups because it takes time to determine the importance and permanence of accomplishments and because there is insufficient space to cover all of the developments of more than thirty years.

Outstanding among these inventors was Thomas Midgley, Jr., who gratefully acknowledged that without "Boss Ket's" encouragement he would not have succeeded in inventing ethyl gasoline. Later, confidently sponsored by Frigidaire Division, he and Dr. Albert L. Henne solved the problem of a safe refrigerant by inventing Freon-12, now universally used. Subsequently he pioneered in modern mining of the sea for rare chemicals.

Encouraged by "Boss Ket," Caleb E. Summers developed the harmonic balancer now universally used to damp torsional vibration in engines. He made the invention under compulsion of the patent laws because, when General Motors was denied a license to use the now obsolete Lanchester friction damper, he would not accept the view that there was no different and better way to solve the problem of torsional vibration. Later he invented tin plating of pistons to eliminate the need for long engine break-in. With Thomas C. VanDegrift he invented the first successful crankshaft balancing machine suitable for large production. Mr. VanDegrift and his assistant E. J. Wolff in turn led an extraordinarily capable group of engineers in the development of production balancing machines for many purposes.

Another of "Boss Ket's" men, Alfred L. Boegehold, now assistant to the vice president in charge of the Research Staff, is a recent recipient of the gold medal of the American Society for Metals for his achievements in metallurgy. His work in powder metallurgy led to the establishment of Moraine Products Division of GM. He has made important inventions in a number of fields including malleable iron and engine bearings. Under his stimulating leadership Research Staff metallurgists have recently made such important inventions as the Aldip process of aluminum plating and the GMR-235 alloy used for very high temperature, jet-engine turbine buckets.

Other men who have accomplished much under "Boss Ket's" leadership are: Dr. E. J. Martin and Dr. G. M. Rassweiler and their associates in the field of instrumention; Harry C. Mougey who made possible the development of Duco which revolutionized automobile body painting and, in cooperation with H. R. Wolf, found the clue which led to the development of extreme pressure lubricants essential in final drives; Ernest Wilson who invented the resonance silencers now used on most automobile engines; John O. Almen who led the engineering profession in his studies of residual stresses and, with George E. A. Hallett, did the pioneer work in the development of hydraulic valve lash adjusters now widely used; and William M. Phillips who successfully promoted the first production use of chromium plating in the automobile industry and subsequently invented a bright copper plating process now widely used. Nor should we forget Charles R. Short whose rubber V-belt is used on all automobiles. All this is surely sufficient evidence that "Boss Ket's" friendly, courageous leadership produced far more new developments in more fields than he could possibly have made himself.

Another outstanding leader in GM was Earl A. Thompson who, coming out of the West where he was a college professor and operator of a private irrigation project employing pumps of his own devising, brought with him the principle of the synchromesh transmission. Later—again in the midst of the depression as in the case of the Diesel development—Mr. Thompson led an unusually capable group of engineers in the development of the Hydra-Matic automatic transmission, the first successful fully automatic transmission. This team, like the Diesel team, worked nights and weekends on depression-limited budgets and achieved outstanding success. In more recent years, under the inspiring leadership of Oliver K. Kelley, another very capable, hard working group in GM's Engineering Staff leads the world in automatic transmission development.

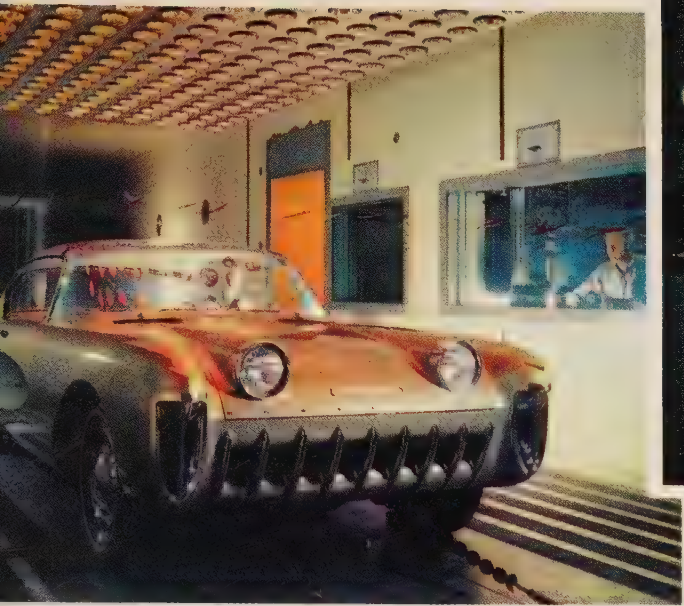
The Challenge: To Build On Yesterday's Inventions

The existence of the splendid buildings and equipment of the Technical Center might suggest that the problem of developing many new and advanced products is more than half solved and all that remains is to hire enough engineers and scientists to do the work. The problem, it might seem, is like that of the factory: to get more production one must build more buildings, buy more machinery, and hire more people, and the result is more production. This leads to the next conclusion that before long some kind of automatic machine will be developed to make inventions without human effort.

Instead, is it not far more likely that it will be the man with the inquiring mind, working in a friendly, encouraging atmosphere where his ideas can be developed, who will continue to produce the new inventions?

Listening to the true stories of engineers and scientists like those mentioned makes one aware that inventors are an unusually capable group of men who do their best when the enterprise is under optimistic and courageous management. Inventors' enthusiasm and fresh points of view are stimulating, and the patent lawyer's contacts with inventors become one of his greatest sources of pleasure.

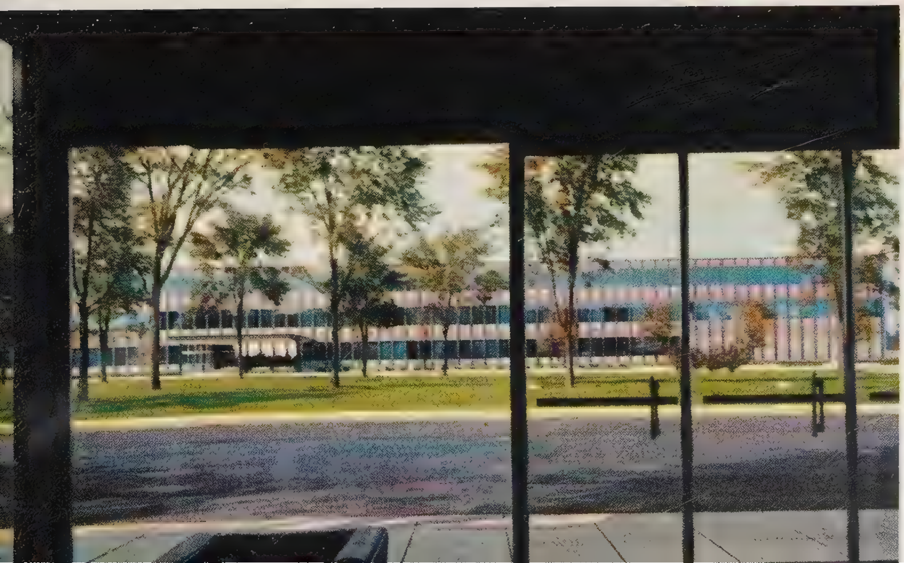
While many of the earlier inventors remain active, a new generation of engineers and scientists now has moved in to add to the inventive process with their inquiring minds. Their traits are, in most ways, similar to their predecessors; only the problems which they attack are different. There is no apparent end to the need for them to solve the many vexing technical problems. Such men may well be proud of the achievements of their inquiring minds and the recognition it brings them.



Conditions duplicating a car traveling 100 mph in temperatures up to 150° F can be produced in the Research Staff wind tunnel. ★

Products and experimental designs are viewed and evaluated in the huge hemispherical-shaped Styling auditorium.

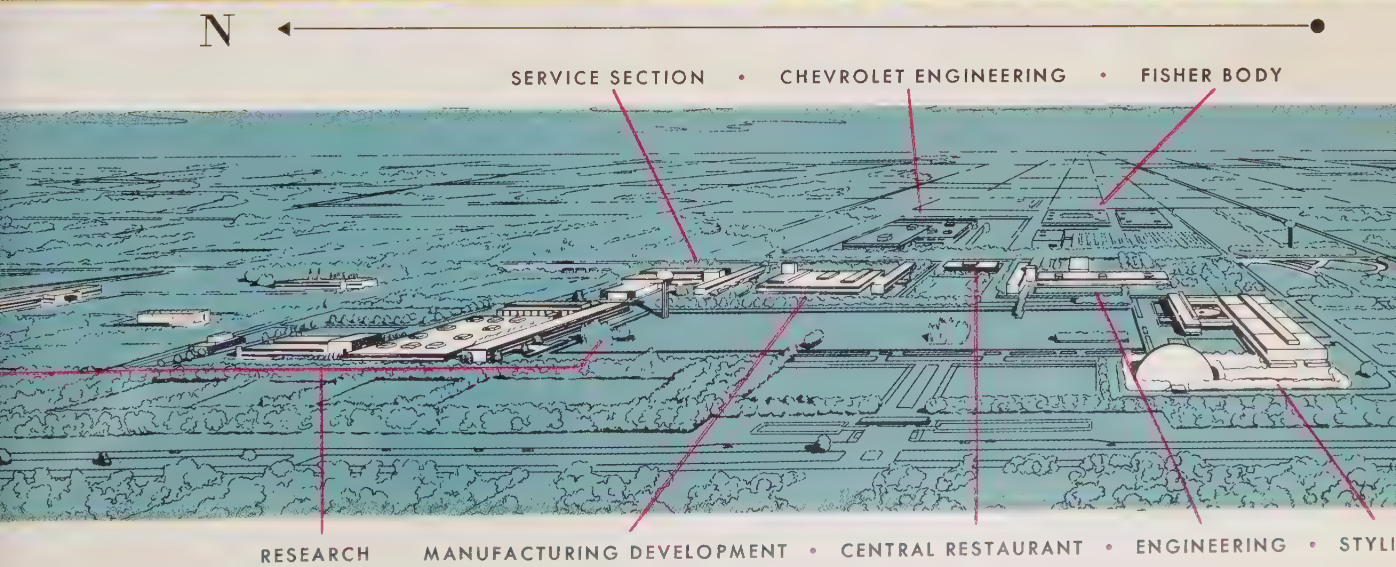
Critical measurements are made on experimental parts in dust-free, well-lighted areas in the Engineering Staff Shop Building. The view from these inspection areas is a colorful patio at the edge of a seven-acre artificial lake.



The Manufacturing Development Administration Building as seen from the lobby of one of the Engineering Staff buildings across the mall.

GENERAL MOTORS TECHNICAL CENTER

While the architecture of the General Motors Technical Center intends to reflect tomorrow's industrial environment where surroundings would be beautiful as well as functional, to more than 4,000 men and women it is a place where their inquiring minds can explore the future. The Technical Center occupies the central 320 acres of a General Motors-owned area of some 900 acres at Warren, Michigan, just north of Detroit. It includes four Central Staff organizations—Research, Engineering, Styling, and Process Development. There is also a Service Section which maintains the buildings and grounds. Grouped around a 22-acre lake are 25 buildings ranging from gatehouses to large laboratory, office, and shop buildings; floor space totals 2,250,000 sq ft. Connected by over a mile of underground tunnels, the buildings contain some 380 miles of electrical wiring, over 12 miles of duct work, and 56 miles of fluorescent tubing. There are 11 miles of roads and parking space for 3,000 cars. The landscape plan called for over 13,000 trees to be planted, some 60 ft high, and more than 60,000 ground cover plants and shrubs. Adjacent to the Technical Center on the east are the Fisher Body Division Central Offices and the Chevrolet Motor Division Engineering Center.


N
SERVICE SECTION • CHEVROLET ENGINEERING • FISHER BODY
RESEARCH
MANUFACTURING DEVELOPMENT • CENTRAL RESTAURANT • ENGINEERING • STYLI

Looking west toward the main entrance of the Styling Administration Building. In the background is the aluminum-clad dome of the Styling auditorium.

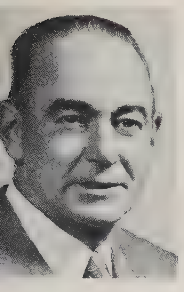
★ This advanced experimental foundry has played an important role in the outstanding contributions of Research Staff metallurgists.

The Engineering Staff tests elliptical leaf-springs for durability on this automatic cycling machine. ★

★ This 67-foot-long semi-automatic machine (below) was designed and developed by the Process Development Section for assembling 51 parts in the Hydra-Matic automatic transmission.

Manufacturing in General Motors

By JOHN J. CRONIN
Vice President
in charge of
Manufacturing Staff



BY ITS ROOTS the word "manufacturing" would suggest making by hand. Fifty years ago this connotation of the word was true for the most part, for at that time the majority of manufacturing was done essentially by hand. Machine tools, mass production techniques, and other labor-saving devices as we know them today were things of which few men in that era even dared to dream. While we recognize that the human element can never be divorced from manufacturing, more and more emphasis is being placed on the substitution of brain power for muscle power as we strive daily to improve still further our manufacturing methods and processes. And so, as in other fields, a never-ending search goes on; a search for the ideal way, *the best* way to manufacture the product.

However, like most fields of technology, manufacturing, too, is becoming more complex, and to effect further improvements in this phase of business requires the knowledge and skills of people with technical training. For example, 35 years ago most of the structural members in automobile bodies were made of wood and fastened together with screws. A simple, hand screwdriver was used to perform this operation. It was not long, however, before the hand screwdriver was replaced by a motor-driven one which greatly improved the efficiency of the operation but required the skill and knowledge of an electrician to keep it in repair. If we multiply this simple illustration of increasing complexity by the myriad of similar cases that have taken place over the years, we can get some idea of the complexity in manufacturing today.

In essence, manufacturing begins where product design ends. The production engineer has the task of translating the design engineer's drawings into an assembly of parts that has form and dimension and, more importantly, value to the user. Whereas the design engineer is concerned with the size, shape, and materials of the product per se, the production engineer must consider such aspects of producing the product as the most effective use of floor space, proper selection of machine tools, flow and handling of materials, production rates, procedures and schedules, and production efficiency in order to manufacture a quality product at a profit. Indeed, manufacturing today is a complex process.

Stated simply, however, manufacturing is the mass reproduction of the products conceived by design engineers according to the highest standards of quality at the time, the place, and in the quantities required by the market—and at a profit. This defination is perhaps oversimplified, but, I believe, it reflects our basic manufacturing philosophy in General Motors.

Consistent with General Motors organizational plan of decentralized authority and responsibility, the management of each GM Division is directly responsible for its own manufacturing results.

The welding of a variety of engineering skills into a smoothly functioning unit is the concern of each Divisional general manager. As individuals, production engineers form the manufacturing team whose job is to produce the product at the lowest possible cost consistent with high quality, in volume, and in line with the requirements of the market. This team-work process includes cooperating with the other functions of the business, such as design engineering, sales, personnel, finance, and accounting. Through such cooperation in discharging its authority and responsibility, the manufacturing team of each Division of General Motors decides for itself which parts of the product it will make and which parts it will buy; how those "made" parts are to be processed; the determination of machines and facilities needed; the design of the tools required; the establishment of sequence of operations; the scheduling of purchases; and the production rates at which the facility will operate to meet the schedules issued by the Central Staff.

Although emphasis has been, and will continue to be, placed on decentralization of manufacturing responsibilities, there are areas of common interest in consideration of policy matters relating to manufacturing which naturally require a group, a staff group, to lead development in these areas. The Manufacturing Staff serves in that capacity.

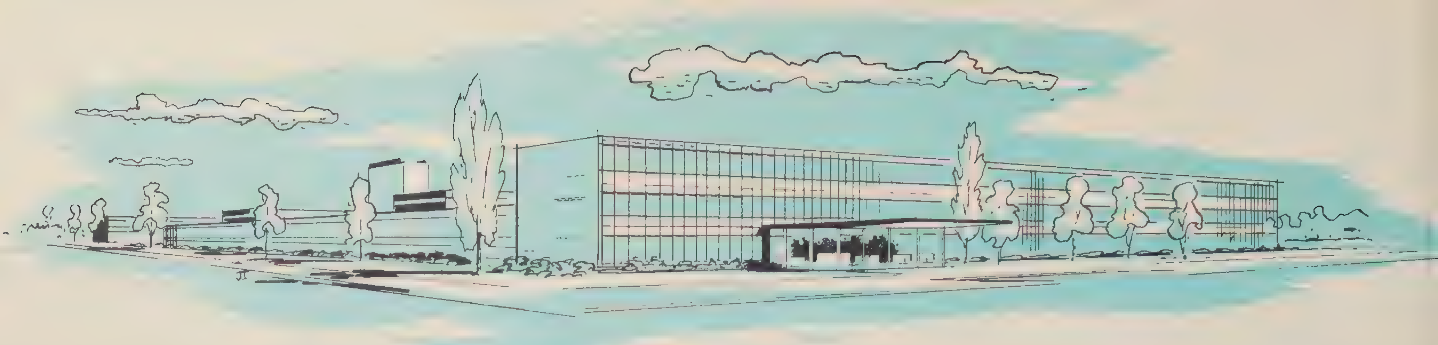
Like other Staff groups, we exist to give sevice, counsel, and advice to higher management and to the operating Divisions on matters pertaining to manufacturing. In the formulation of policy, the Staff serves to study and summarize problems in the manufacturing field on behalf of the Divisions, or for presentation to the Manufacturing Policy Group.

This body, which is an advisory group to the Administration Committee, is made up of both staff and operating executives of General Motors who bring to bear upon the problem a broad background of experience and "know-how." The Manufacturing Staff, acting in a liaison capacity between the Divisions and top management, may direct questions of policy to the President, or in other instances, to the Manufacturing Policy Group.

In addition, the Staff has two other functions. One is to provide certain services to other Staffs and Divisions. The second is to study, explore, and develop matters of common interest in manufacturing problems in cooperation with General Motors units. In fact, we often tell the GM Divisions that we like them to think of the Manufacturing Staff as merely an extension of their own organizations.

Procurement and Scheduling

In the area of providing services the Manufacturing Staff gives assistance to GM's manufacturing units in the procurement of materials and in the forecasting of production requirements. Close coordi-



nation between procurement and scheduling is essential in manufacturing, particularly in multi-plant operations, if a smooth, efficient flow is to be maintained to and from the manufacturing facilities.

Our direct responsibility in procurement is limited to such activities as are necessary to assure that the over-all requirements of General Motors for prime materials are met. For instance, when the quantity needs of General Motors are of such volume that central procurement is advantageous both to GM's Divisions and our suppliers, then that item is usually purchased by contract through the Manufacturing Staff's procurement facilities. With few exceptions, central procurement, however, is normally restricted to basic raw materials.

The Staff also prepares forward schedules and related data of car and truck production for the Divisions. These schedules are prepared as directed by top management from data furnished by the Distribution Staff and by the sales staffs of the several car and truck Divisions.

In this area an important consideration in our operations is the movement of freight. We like to think of the road equipment, both the railroad cars and the trucks that haul our goods, as simply an extension of our own conveyor lines, and as such they are a vital element in our planning. It is essential that we have the right goods at the right place at the right time, and efficient use of freight facilities not only keeps the flow of materials on time, but also reduces storage, handling, and inventory of goods in process.

Facilities and Processes

While the Procurement and Scheduling activities of the Manufacturing Staff are concerned with the flow of raw materials to and finished products from our plants, our Facilities and Processes group attends to a variety of needs directly connected with the manufacturing operations.

Most of these activities are carried on through a number of production engineering committees composed of representatives from our manufacturing Divisions and our own Staff. Through these committees there results a marked degree of teamwork, effective pooling of ideas, and interchange of information so that each Division has available to it General Motors latest findings in all areas of manufacturing.

The primary responsibilities of the Manufacturing Staff in this committee work are to conduct independent studies, provide counsel and advice on manufacturing problems, and to correlate and publish the results of the committee work.

In the area of production engineering these committees have developed standards for materials, tools, processes, and electrical and hydraulic equipment for machine tools.

Work Standards and Methods Engineering

Even the most elaborate manufacturing facilities are of little value unless there are trained people to operate them efficiently according to prescribed methods. In this important area the Manufacturing Staff sponsors a number of other committee activities similar to those in production engineering. One objective here is to establish standards for man-machine relationships and for a variety of indirect activities such as inspection, materials handling, and maintenance where it is practical to do so. A second objective in these committee activities is to stimulate new thinking in the field of methods engineering.

In General Motors we think of methods engineering not only in the light of studying and planning the motions involved in man-machine relationships so as to minimize manual effort, improve quality, and lower cost, but also in the light of applying the same principles to all phases and types of work both in manufacturing and other areas of activity as well.

Manufacturing Development

I mentioned previously that manufacturing is growing increasingly complex. This is due mainly to the continued application of advances in science and engineering to product design. If we are to continue to progress in the manufacturing area, more and more technically trained people will be required to apply the fundamentals of science and engineering toward improving our present methods and processes and toward developing new manufacturing concepts as well. While all of GM's manufacturing units have sizable production engineering groups to cope with a multiplicity of manufacturing problems, the Manufacturing Staff's Process Development Section was organized to provide assistance to these groups.

The Process Development Section, with facilities at the Technical Center, is primarily a manufacturing development group, composed of engineers and scientists, devoted to applying the "engineering approach" to methods and processes of manufacture. Like the other segments of the Manufacturing Staff, the facilities of this group are at the disposal of any manufacturing unit in General Motors.

Summary

I might sum up the philosophy of the Manufacturing Staff's operations by re-emphasizing that in General Motors where responsibility and authority are delegated to our decentralized operations, a maximum degree of initiative in finding new methods, operations, and manufacturing skills, is constantly being encouraged. We endeavor to carry out this theme through our committee activities and through our facilities at the Technical Center.

So, the goal of manufacturing is to produce the products of our design engineers according to the highest standards of quality at the time, place, and in the quantities required to satisfy our scheduling—and at a profit. This is manufacturing in General Motors.

Manufacturing Staff Facilities

By RODGER J. EMMERT
General Motors
Manufacturing Staff

The growing complexity of production techniques today places strong emphasis upon the need for applying science and engineering to those techniques if further progress is to be made in manufacturing. To provide a place where engineers and technicians can search out and develop practical methods for better manufacturing processes, a new facility has been completed at the General Motors Technical Center. Known as the Manufacturing Development Building, it contains expanded facilities for the various technical units of the GM Manufacturing Staff. New information relating to the physical sciences of chemistry and physics, metallurgy and spectroscopy, electrical engineering and electronics is being studied and applied by these units toward improving manufacturing methods. Laboratories, therefore, form the core of the developmental activities. Adjacent work shops provide equipment and areas for practical solutions to the problems of working out better manufacturing processes. The balance of the facilities provide design, drafting, and conference rooms where a variety of technical problems can be solved for the benefit of manufacturing activities everywhere in General Motors.

Laboratories and shops for developmental work on newer and better manufacturing processes

To achieve the purpose of rendering assistance to General Motors Divisions on problems related to manufacturing methods, the Manufacturing Staff has four activities centered in an attractive, modern building at the Technical Center. These activities are:

- Process Development Section
- Production Engineering Section
- Work Standards and Methods Engineering Section
- Power Section

Process Development Section

The Process Development Section functions to search out and develop better manufacturing processes. Laboratories form the core of the Section's facilities, and its shops are utilized for the practical solutions to problems that develop in such manufacturing processes as metal cutting, metal casting, welding, heat treat, plating, metal polishing, painting, and assembly.

The extensive laboratory and work shop facilities permit engineers to develop specific information in the fields of science and manufacturing processes. A single-story structure annexed to the three-story administration building, provides facilities for this developmental work. By grouping the laboratories together in the center of the building with work shops located around them, it was possible to arrange air conditioning and utilities in the most efficient manner.

Basically, four departments form the Process Development Section in which engineers and technicians apply the fundamentals of such physical sciences as chemistry, physics, metallurgy, and

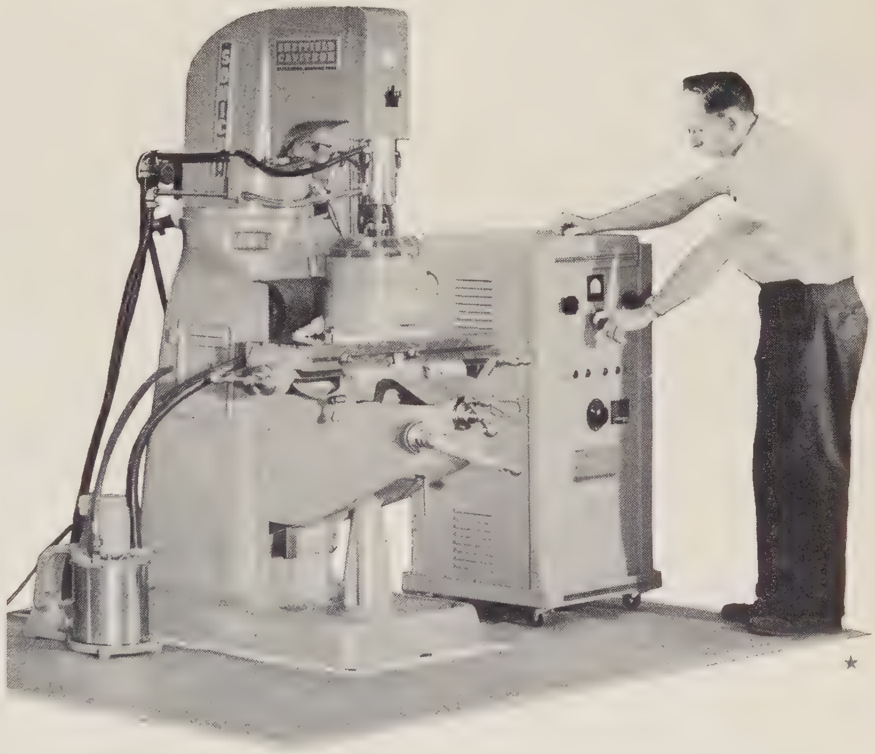


Fig. 1—The Mechanical Work Shop of the Process Development Engineering Department contains a high capacity, high frequency "Cavitron" machine which has proved useful in piercing holes in very hard materials, such as glass, hardened steels, carbides, ceramics, and diamonds, by using ultrasonic waves to propel abrasive grit against the work. The head of the machine vibrates at approximately 20,000 cycles per second. These vibrations are amplified by the conical shape of the head which increases the amplitude of the vibrations as they advance toward the smaller diameter end of the head. The erosion of the hard material is accomplished by flooding the piercing tool with lapping compound. The abrasive is drawn under the tool and forced out again at this terrific vibration rate of 20,000 cycles per second.

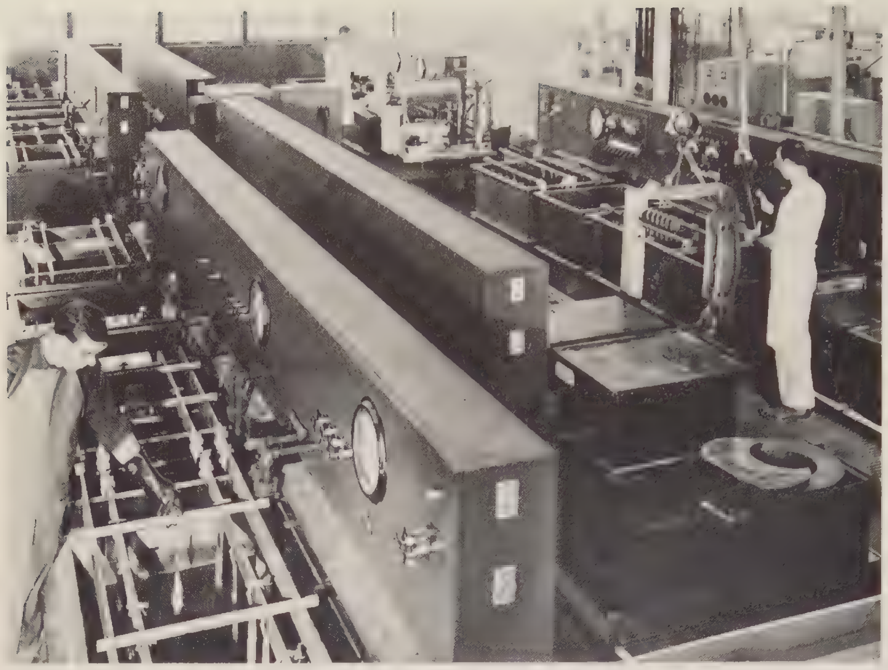


Fig. 2—The Plating Shop of the Chemistry and Metallurgical Department is equipped with dip tanks averaging 3 ft by 4 ft by 4 ft. These are lined with a plastic material, high temperature rubber, stainless steel, lead, and acid proof bricks. Ten power supplies, used in single units or in multiples, have a total capacity of 11,000 amp. Experimental plating and pilot process operations using almost any plating or chemical treatment solution can be undertaken here.

life, surface finish, and productivity and by determining applications for machining exceedingly hard materials.

Also in the Mechanical Shops are several types of welding equipment together with their controls to facilitate the evaluation of various welding methods applied to production joining problems and the development of improved techniques to produce higher quality welds by more economical methods.

The use of oils in high pressure hydraulic systems or equipment located near high temperature melting pots or open flames constitutes a particular hazard to employes, and the Hydraulics Engineering Group, whose facilities are also in the Mechanical Shop, has undertaken to evaluate all kinds of substitute fluids proposed for use in such systems. Tests have been run to evaluate the effect of non-flammable hydraulic fluids on various types of hydraulic components, from which information on the best types of pumps available and the safest fluids to use was developed for use by the operating Divisions.

electronics to manufacturing problems. These Departments are:

(a) The Engineering Department
(b) The Chemistry and Metallurgical Department
(c) The Electronics Department
(d) The Foundry Engineering Department.

The Engineering Department

Groups specializing in manufacturing methods, assembly, and inspection form the Engineering Department. In addition to offices and design and drafting rooms, there is a variety of project shops with facilities for metal finishing, tumbling, abrasive polishing, precision gaging, welding, and electrical testing.

The Mechanical Work Shop has facilities for developmental work in the machining of metals. For example, a specially equipped automatic lathe is available for machinability test work on high-speed turning operations. By utilizing ultrasonic waves to propel abrasive grit against the work, the "Cavitron" can machine cavities in extremely hard and brittle materials such as Carboloy and synthetic sapphire (Fig. 1). Such experimental work is designed to assist the Divisions by evaluating various machining techniques to improve tool

Fig. 3—Electronic equipment, as applied to all phases of process and machine development, is engineered, developed, and tested in the laboratories of the Electronics Department. The servomechanism machine in the laboratory pictured here has wide application in the design of controls for automatic equipment. The feed-back principle is being used to advantage in the design of such equipment.

The Paint Shop is equipped with spray booths, a mechanical conveyor through and around the largest booth, and a large oven for drying painted panels at controlled temperatures. All types of paint mixers and mechanical pumps for handling paint have been provided. Equipment is available for spraying paint at considerable pressures and at elevated temperatures. Associated with the electrostatic application of paint is the problem of getting suitable high-voltage generating equipment, but this group, in cooperation with the Electronics Department, has developed generators which supply direct current at high voltages and which incorporate safety devices limiting the flow of current, thus making them safe with regard to fire hazard and injury to employes.

Experimental equipment for use in developing better methods for polishing decorative hardware has been installed in another area. Polishing of certain types of parts to be electroplated formerly required great physical effort and resulted in quite dust-laden work areas. Abrasive polishing equipment for a process called Gyrofinishing now has been developed by the Process Development Section. The experimental unit consists of a rotative drum in which free abrasive mixtures of various materials rotate at high surface speeds. Parts to be polished are placed on fixtures which lower them into free abrasive, dragging them through the abrasive and rotating them to expose all surfaces of the part to the polishing medium. This experimental work has enabled Process Development engineers to design a number of high-production machines for handling automotive hardware, zinc die castings, and the smaller sizes of body trim. A recent development to utilize this polishing process is a horizontal rotating drum-type machine to handle the larger decorative trim parts; it is equipped with a conveyor for handling the parts into and out of the rotating drum.

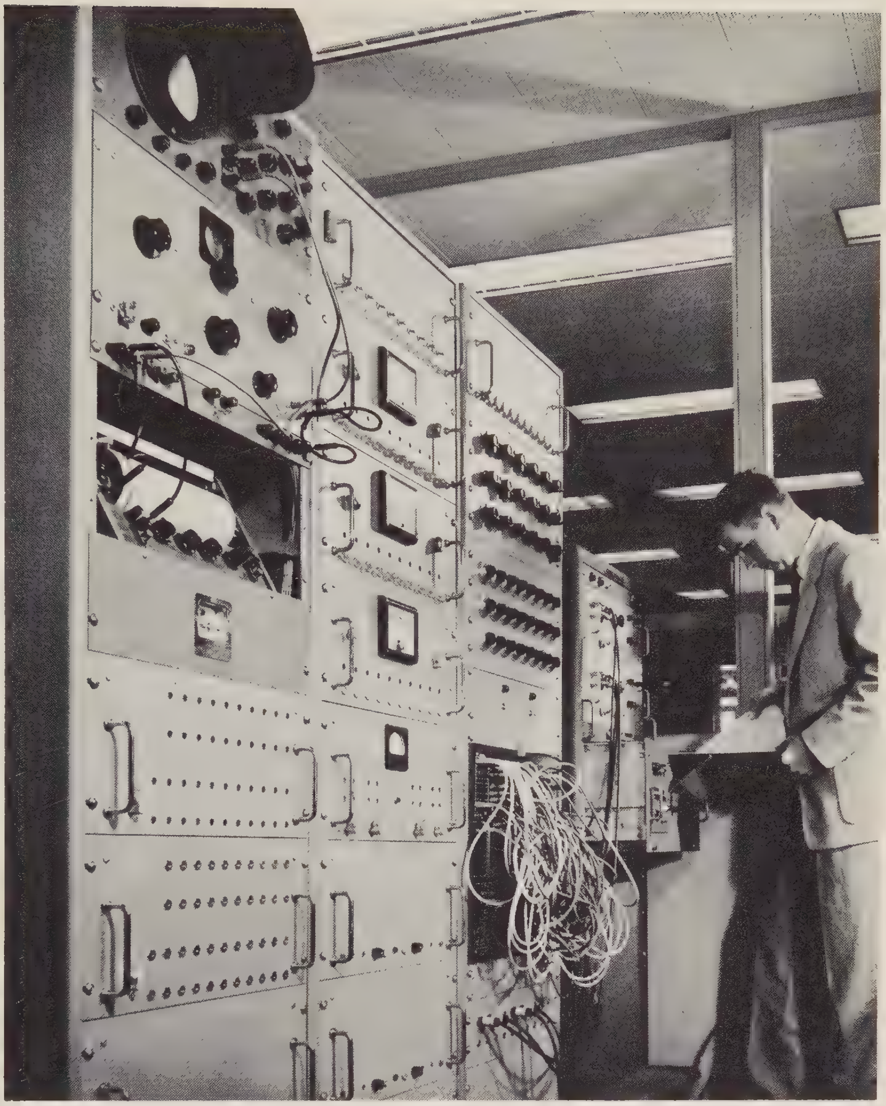


Fig. 4—This electronic analog computor is used primarily in the solution of engineering problems which require a lengthy and, in some cases, highly complex mathematical analysis. It is available not only for the use of the Manufacturing Staff and the other Staffs at the Technical Center, but to all General Motors Divisions.

The Chemistry and Metallurgical Department

In the fields of chemistry, metallurgy, and plating skilled technicians of the Chemistry and Metallurgical Department undertake developmental projects for the Divisions, as well as assisting the Foundry and Engineering Departments of Process Development.

Hardening and annealing furnaces in various sizes provide a large variety of heat treating facilities for such surface treatments as nitriding, carbo-nitriding, gas carburizing, and the bright hardening of stainless steel.

For the induction heating of metals there is high frequency power generating equipment ranging from 5 to 25 kw, 48,000 cycle units up to 150 kw, 9,600 cycle units. These are suitable for the rapid induction heating of parts requiring hardening, brazing, or copper impregnation. One project undertaken here was the development of a process and the equipment for copper impregnating hydraulic pump rotors made of powdered iron to increase the strength of these rotors. The process involves the induction heating of the rotors to brazing temperature in a matter of seconds under controlled atmosphere. Mechanical equipment handles the parts through a furnace, into and out of the induction coils, and through a cooling zone to reduce the temperature low enough to avoid oxidation when exposed to the air.

In the Spectrographic Laboratory there is metallographic equipment capable of producing photographs of grain structures to a high degree of magnification. A two-meter grating spectrograph makes rapid determinations of the composition of metals.

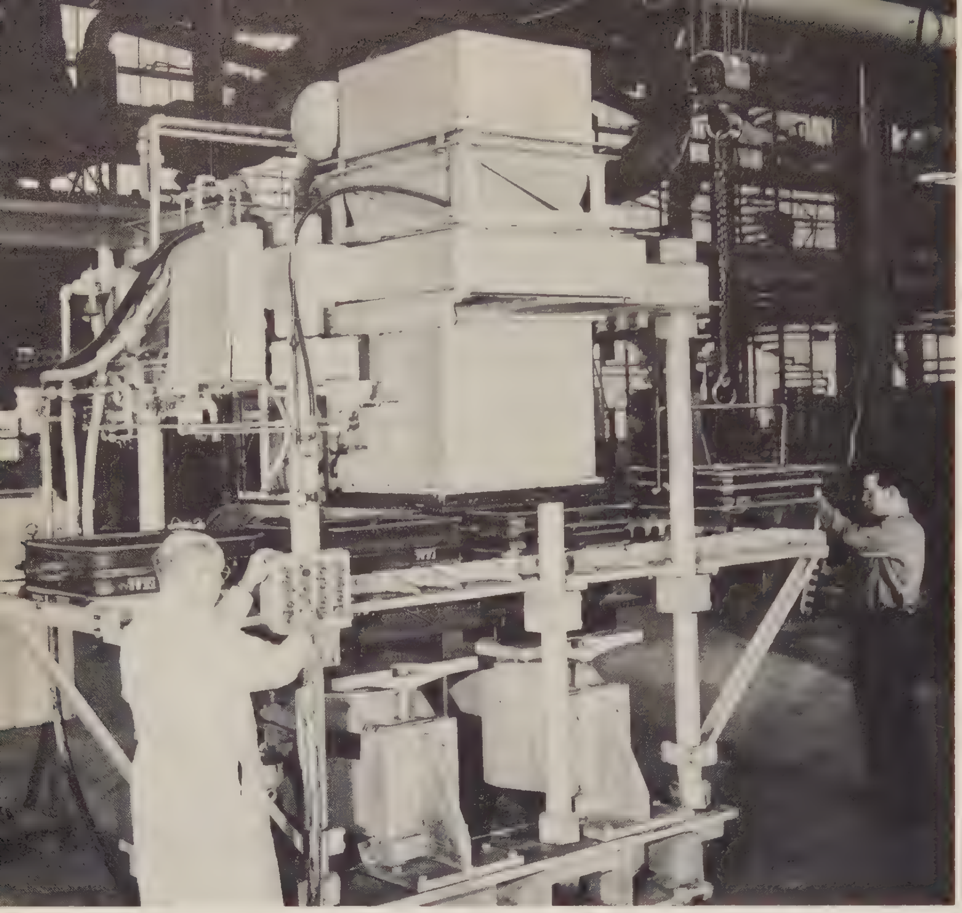


Fig. 5—This semi-automatic blow squeeze molding machine was designed and developed by the Foundry Engineering Department. Its production capacity of 240 molds per hour is considerably higher than conventional molding machines.

The Chemical Laboratory is completely equipped to furnish analytical data gained from investigations of new materials and processes to the operating Divisions and the various engineering groups at Process Development. A Plastics Laboratory also has been established to investigate the use of plastic materials as manufacturing tools.

In the Physical Testing and Metallography Laboratories materials are examined and tested for internal structure and for physical characteristics. Metallographic and macrographic cameras, microscopes, and darkroom facilities are provided for the study and recording of samples. A 300,000-lb tensile test unit, an impact test unit, and hardness testers are available, as well as an ultrasonic transmission tester for inspecting defects in metals.

The Plating Shop is equipped with dip tanks of sufficient size to plate most parts customarily used on automobiles (Fig. 2). Such experimental work as electroless nickel plating of intricately shaped parts and hard chrome plating of engine cylinders and piston rings has been accomplished here. The rotors formerly used in the axial compressors of the Allison jet engine were made of stainless steel which is difficult to forge and machine and which required large amounts of nickel; however, a process was developed whereby a uniform thickness of nickel could be chemically distributed on all areas of carbon steel rotors irrespective of their shape. Also, a method for plating hard chrome on the circumferential surface of steel piston rings was developed, and such rings are now regularly used in General Motors Diesel engines.

The Electronics Department

The Electronics Department is provided with a variety of equipment, including computing and ultrasonic machines, used in the development and testing of electronic equipment for application to all phases of processes and machine tool development.

The Instrumentation Laboratory has equipment for measuring and recording displacement, velocity, acceleration, temperature, pressure, strain, or most any physical variable. A number of dynamic variables can be recorded simultaneously to establish fundamental relationships. Results are used in developing improved manufacturing equipment and processes.

The Servomechanisms Laboratory is equipped to develop, design, and build electrical and electro-hydraulic servomechanisms for use on automatic equipment (Fig. 3). Special instruments, such as function generators, derivative-integral filters, ultra low-frequency oscillators, and an ultra low-frequency rejection filter, are available to optimize servo system designs. Mockups of actual systems can be made using some of the special purpose components which consist of synchros, synchro transmitters, synchro transformers, resolvers, servomotors, servo amplifiers, feedback transducers, and mechanical components. The 10 gal per min, 2,000-psi hydraulic power supply enables high-power electro-hydraulic servomechanisms to be investigated.

The Physics Laboratory equipment includes complete precision optical benches with a collimator and accessories for checking definition of lenses, as well as focal length and speed of lenses. Concave reflecting gratings and prisms for use in spectroscopic work, a complete line of light sources for work from the infrared to the ultraviolet, and two complete sets of filters are also available. Vacuum equipment is provided capable of giving vacuum of 0.1 micron or better. A quiet room affords approximately sixty db attenuation from most outside noises for sound and vibration studies.

Another laboratory is equipped with an electronic analog computer which has 30 operational amplifiers, four multipliers, four function generators, and an X-Y plotter available for computation, function generation, and recording (Fig. 4). This computer is particularly adaptable for solving systems of complex simultaneous differential equations and is very useful in the dynamic analysis of engines, machinery, vibration problems suspension systems, servomechanisms, and hydraulic systems.

The Ultrasonics Laboratory is designed for developmental work on non-destructive testing equipment, inspection of mechanical units for evidences of failure, and determination of methods and facilities for cleaning of parts.

The Standards Laboratory calibrates and maintains the equipment for the Electronics Department. This laboratory also conducts studies on the development

Fig. 6—Manufacturing Staff activities at the Technical Center are located in this Manufacturing Development building. A three-story Administration Building contains offices, drafting rooms, an auditorium, and a library totalling 78,872 sq ft of floor space. The adjoining one-story building to the rear contains the laboratories, work shops and project areas covering 187,825 sq ft. Foundry activities occupy approximately 53,000 sq ft of this area.

and application of extremely precise measuring devices.

The Foundry Engineering Department

The experimental foundry is the largest shop area in the Process Development Section, covering an area of approximately 53,000 sq ft. The area includes a cleaning room, core room, shell molding facilities, melting area, and a production molding line. Its conveyor system is capable of handling the largest flasks regularly used in General Motors foundries. Facilities have also been provided in this section of the building for the future installation of a cupola when and if larger volumes of metal are needed in the foundry.

Sand handling equipment is so constructed that it can handle four different grades of molding sand and can deliver the sand by means of air ducts and belt conveyors throughout the foundry as required. A laboratory for the determination of the physical properties of molding and core sands is a very important part of this facility. The foundry is equipped with three electric furnaces with a melting capacity of 1,000 lb per hour and capable of holding at pouring temperatures 1,500 lb of metal.

This foundry group has developed and designed a semi-automatic blow squeeze molding machine to produce molds at the rate of 240 per hour which is presently being tried out under operating conditions (Fig. 5). This machine not only has a higher productivity rate than conventional jolt squeeze machines but will reduce undesirable noise and, because of the nature of the operation and equipment, will reduce maintenance cost.

Development of a method of reclaiming foundry core sand is another example of the work of this Department. Experimental equipment was set up to obtain data on a suggested method of salvaging core sand. Previously this material has been hauled away from foundries and dumped, but it is becoming more difficult to find appropriate space for dumping and more costly to haul this material long distances. The contemplated process was successful, and sufficient data was obtained to design equipment sufficiently large to handle the quantity of core sand developed daily in GM foundries.

Other Manufacturing Staff Sections

Due to the nature of their activities, the work of the Production Engineering, Work Standards and Methods Engineering, and Power Sections requires mainly offices, drafting space, and meeting rooms of various sizes. The Administration Building provides these facilities as well as an auditorium seating 242 persons, and a library (Fig. 6).

The Production Engineering Section works through committee activities which can be divided into two main groups, one dealing with mechanical problems and the other dealing with metallurgical and chemical problems. Each group is made up of several committees consisting of representatives from each of the operating Divisions and is organized along the lines of functional activity. Committees handling problems associated with master mechanics, plant engineers, quality control, and material handling are associated with the first group. The second group is divided into the Metallurgical Committee with sub-committees for foundry and forging, and the Chemical Committee with sub-committees dealing with plating, painting, lubrication, and industrial waste.

The Work Standards and Methods Engineering Section also accomplishes its work largely through committees made up in a manner similar to those of the Production Engineering Section.

The Power Section consists of engineers who function essentially as consultants in the design and construction of the steam generation and power distribution systems in GM plants.

Conclusion

It is apparent that manufacturing in the automobile industry is becoming less and less the work of using hand tools, and more and more a process of utilizing machinery and technical "know-how" to accomplish results. Successive developments constantly reiterate the fact that there must be more intense application of the physical sciences—physics, chemistry, metallurgy, and mechanics—for they are the foundation upon which progress in manufacturing is constructed.

The new manufacturing development facilities at the Technical Center combined with the skill and knowledge of the engineers and technicians who are using these facilities will result in the solution of many complex manufacturing problems that occur in General Motors.

Production, Methods Engineers Join in Advancing Manufacturing Technology

By GLEN R. FITZGERALD
and ROBERT D. McLANDRESS
General Motors
Manufacturing Staff

Among many unexplored routes, which one is the shortest?

Few of today's products could be manufactured in volume with manufacturing facilities of a decade or two ago. The manufacturing function requires continuing engineering advancement to keep the cost down, to maintain quality, and meet production requirements in the face of increased complexity of design. At the GM Technical Center production engineers and methods engineers are joined in this striving for progress. On the Manufacturing Staff the production engineers of the Process Development Section develop machinery for making the end products, and methods engineers of the Work Standards and Methods Engineering Section work with them to insure that facilities which are recommended or completed make optimum use of men, machines, and materials.

Today's automobile user is quite familiar with the tremendous development in automobile design since the product first became popular. His demands upon the product engineers and stylists have produced an evolution in the automobile that is so sweeping as to be almost beyond comparison with most other products. However, he may not realize that a proportional amount of engineering effort was required of production people to keep pace with the efforts of product designers. In fact, the demands upon industry as a whole over the years have resulted in the development of a new field of specialization called production engineering. A related kind of engineering in the manufacturing area is called methods engineering. These men are as interested in the optimum efficiency of production processes as the production engineers but do not design tools for production. Rather, they concern themselves with the optimum interrelationships of the men, machines, and materials of manufacture.

Planning for production in the early days was generally done by a man with a wide background of shop experience. He was familiar with the potential of all standard machine tools, generally having served his apprenticeship in their operation. He was primarily concerned with the ability to produce the components required using the tools and equipment with which he was familiar. If the product design was beyond the manufacturing capabilities of currently available machines, he called upon the machine tool builders to provide improved equipment to do the job. He had no staff of engineers to plan for adequate labor utilization, material handling equipment, or minimum work-in-process inventories. Generally, his main objective was to make effective use of the equipment available even though a premium of manual effort might be required.

Today's planning for production recognizes a tremendously broader range of possibilities. It involves a study not only of the detailed operations involved to produce a given part but of how those operations can be combined, integrated, or arranged to provide a minimum cost of manufacture. In planning for manufacturing the production engineer not only familiarizes himself with machine tools and their capabilities, but recognizes the potential and limitations of special equipment that could be developed for production use. Assisting in this planning function is the methods engineer.

Developments during recent years in machine tools, automatic feeding devices, electronic gaging and sensing devices coupled with feedback control, and other technological advances have considerably extended the range of investigation for the production engineer and increased the potential contribution of the methods engineer. Where in the past there may have been but one way to process a given component or assembly, today this problem becomes one of choosing from a multiplicity of solutions ranging from the use of individual standard machines to the development of integrated lines of automatically controlled special equipment (Fig. 1).

Production Planning Considerations

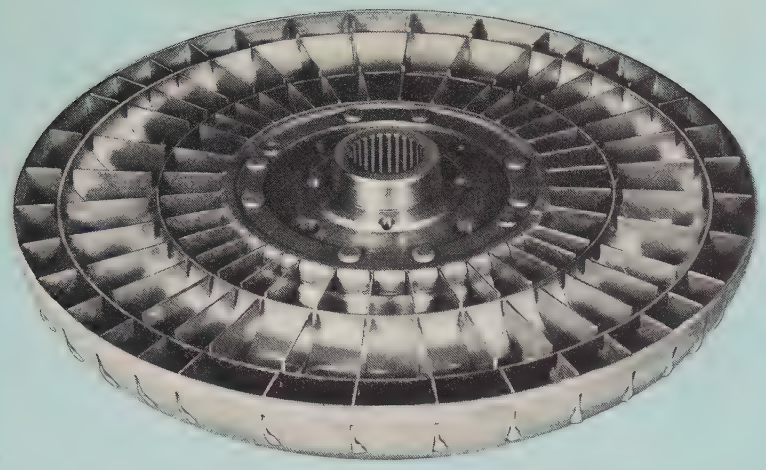
Consideration of such a range of possibilities by the production engineer demands the planning, consideration, and evaluation of many optional methods to insure selection of the best to fit a particular situation, and the methods engineer's help is valued in reaching basic decisions.

From the production engineer's viewpoint the selection involves a consideration of two very broad areas of study.

Economic Factors Affect Technical Solutions

One area is primarily economic and requires a complete analysis of the labor cost of each possible method and its comparison with the equipment investment required. In this area it is important that the production engineer have a basic knowledge of methods engineering. Thus, he should know when to call upon the methods engineer for his assistance in planning the manual portion of the job and in determining labor requirements of different methods. The methods engineer can give attention to work place layouts, material handling methods, balance of labor between operations, and many other details that are considered in a well-planned production line. The methods engineer develops estimated labor costs and can be of invaluable assistance to the production engineer in pointing out the areas wherein the development of special equipment and processing techniques can be productive to the greatest direct labor saving.

The second broad area of study in this selection of processing methods is primarily technical in nature. It involves the relating of product design requirements —such as dimensional tolerances, finish, materials, and function—to all conven-



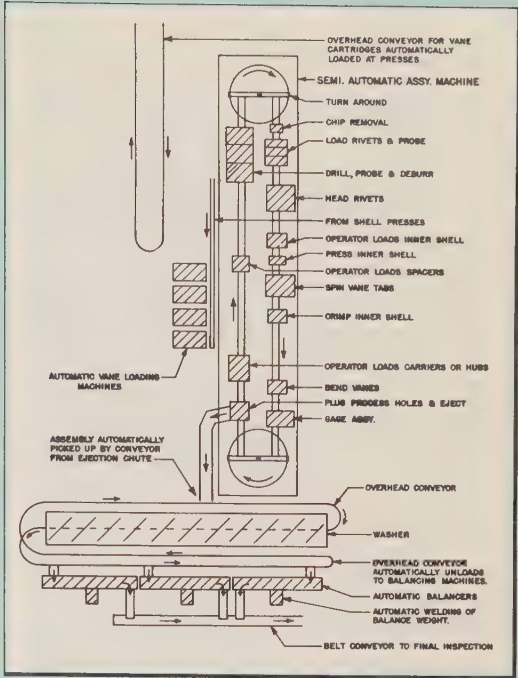
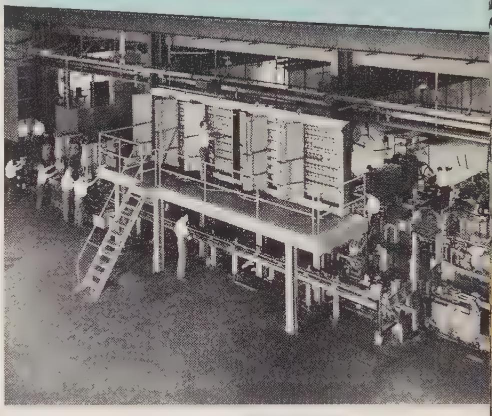


Fig. 1—Volume manufacture of automatic transmission torus assemblies (above) is but one example of the contributions of production engineering. In this case, as shown on the Detroit Transmission Division floor plan (right), vanes and shells come directly from press operations to the semi-automatic assembly machine, designed and built by Process Development Section (below). On the floor plan the process operations are in sequence as indicated, ending with an automatic balancing step. Here General Motors Research Staff equipment automatically detects unbalance and welds a counterweight at the proper spot on the shell periphery as needed.



tional manufacturing techniques. It requires of the production engineer the creative ability to recognize where the developments of scientific research can be applied to go beyond the area of conventional manufacturing techniques.

Major Projects in Three Areas

The need for and desirability of going beyond conventional techniques may be dictated by many reasons. The three most important are:

- To improve product quality at no increase in cost
- To reduce product cost
- To permit meeting new product design requirements for which conventional production processes are inadequate.

Many examples to illustrate developments prompted by each of these three reasons could be cited from records of the General Motors Process Development Section. A completed project in which the major aim was to improve product quality was a special machine for winding wire on a narrow Celeron strip to form resistance elements for automatic gasoline gages (Fig. 2). This equipment is now in use by AC Spark Plug Division. A project in which cost reduction was of principal concern was a special technique developed for the Frigidaire Division to weld two spheres to either end of a slender connecting element to form a connecting rod (Fig. 3). This part is now in use in automotive air conditioning compressors. A recent example of a machine which made possible a product innovation is a glass grinding machine which automatically and precisely establishes three markers which describe a flat plane perpendicular to the beam of Guide Lamp Division's 1956 sealed-beam headlamps (Fig. 4). The plane markers are permanently built onto the face of each lamp by means of three precision-ground glass lugs to which a simple accessory device may be attached for correct adjustment of the light beam.

The development of these three machines required cooperative effort by men in various fields of engineering specialization. In this type of endeavor a familiarity with many fields of specialization is invaluable to the production engineer. He needs to be familiar with new developments in metallurgy, chemical processing, metal finishing, electrical engineering and electronics, hydraulics and pneumatics, and metal cutting. While he may not have a detailed knowledge of these special fields, he recognizes situations in which specialists in these fields can contribute to the solution of his problems.

Process Development Section Objectives

In the General Motors Process Development Section separate groups of specialists have been established to serve the manufacturing development function. These groups specialize in such fields as metallurgy, electronics, chemistry, electrical controls, hydraulics, foundry, metal finishing, metal cutting, painting, cold metal working, welding, and others. The development of a new manufacturing technique or complex piece of special manufacturing equipment usually requires contributions from many of these groups.

While the need for creativity in planning for production is obvious and desirable, it nevertheless must be tempered with a practical approach. The production engineer usually has no opportunity to test the product of his engineering effort on the proving ground or in a test laboratory. Rather, his proving ground is the production line where prolonged shutdown is extremely costly and corrections in design can be made only at the expense of flow of production.

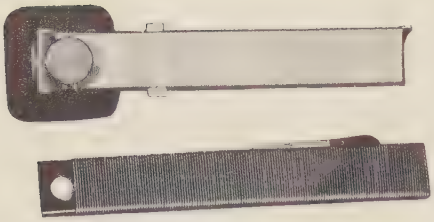
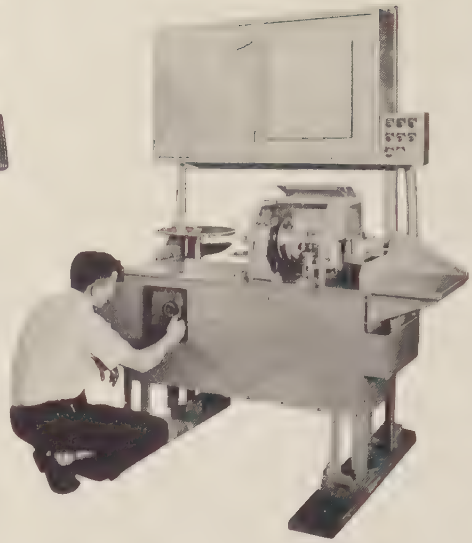


Fig. 2—The accuracy of a gasoline gauge manufactured by AC Spark Plug Division is influenced by the uniformity with which 0.006-in. diameter resistance wire is continuously wound on a celeron strip (above). Spacing of the turns and the tension of the wire determines the linearity of the resistance characteristic of each unit. The special machine (right), designed and built by General Motors Process Development Section to improve the quality of the resistance unit, employs a hysterisis brake to maintain uniform tension on the wire during the automatic winding operation. A signal from an electronic bridge circuit continuously checks the resistance of the strip as it comes from the machine. The continous strip is prepared into unit lengths in another operation.



Progressive management well recognizes this situation and encourages creative thinking by production engineers. At the same time, this situation calls for the patient support of management while the problems which may develop in early production experience are being solved. The willingness of management to cope with early problems to get long term gains is a prerequisite for progress in production engineering.

Probably no phase of the engineered planning for production needs greater emphasis than the economic phase. Many of the technical problems in the development of automatic equipment and even automatic production lines have already been solved. Their ultimate use, however, must be dictated by the extent to which the cost of such equipment can be justified by reducing product cost. Automatic milling machines which can produce complex parts without human attention have already been developed. Their controls, electronically operated from a program punched on paper tape, will consistently operate to extremely close tolerances. However well engineered such machines may be, their use in industry has been limited primarily because the high cost of such equipment can be justified only in a limited number of situations. A great deal has been accomplished in recent years in the development of semi-automatic assembly equipment. Experience in this area led one engineer to make the following statement, "The greatest problems experienced in the development of automatic assembly equipment are usually economic. If the economics are favorable, the mechanical problems are easily solved."

Methods Engineering Contributions

The economic factor further emphasizes the importance of the methods engineer and his place in the planning function. Methods engineers have as their objective to assist in the determination of the optimum economic balance in the use of men, equipment, and materials, as previously mentioned. The methods engineer considers the three cost elements of every production process and seeks out the total by summing up cost increments, however obtained, from each process step. With these data as a base he explores as many operations and combinations of operations as possible with the end objective of arriving at a combination of process steps which keep cost at a minimum. It becomes evident that special automatic machinery is not always the way to optimum product cost. Indeed many plants subjected to methods engineering study are found to have opportunity for considerable cost reduction by means of small improvements to existing processes, and these amount only to fractions of the outlay for a full-scale special machinery program.

Ideally, the economic advantages of special machinery are measured against a yardstick of existing facilities used at optimum efficiency—not against facilities with many inexpensive changes unexplored. From the methods engineer's viewpoint it is insufficient that newly installed processes of manufacture simply result in good quality production at a reasonable profit while amortizing the improved facilities. He can content himself only after approaching the overall cost problem in a methodical way and considering sufficient different possible conditions to insure that proposed improved methods add up to "the one best way now." Once the decision is made, it is too late to wonder how much will be lost, even with improved facilities, because all of the possible methods were not explored.

Production engineers necessarily devote most of their interests to the design of something that will produce a satisfactory part or operation at a predetermined and acceptable rate. Working with him, the methods engineer can insure that major interest also is devoted to determining the methods which require the least time and effort to produce at the lowest possible cost consistent with good quality.

Related to the methods engineer's basic cost consideration, and of paramount importance, is his consideration of the requirements of the individual at his work station. Included in this is a study of such physiological factors as work height, location and design of controls, flow and location of materials, and other working conditions.

The methods engineer is in an ideal situation to question operations which are being considered for production and product design details which affect sim-

Fig. 3—In order for a new product to be reduced in cost sufficiently to find a market, considerable study is given to the production of components and even very small parts. An improved automotive air conditioning compressor manufactured by Frigidaire Division uses five connecting rods in which the ends need to be spherical within ± 0.0001-in. diameter and connected by a slender rod. The prohibitive costs of making this part from solid stock to the tolerances required dictated the development of techniques to permit its manufacture by welding an S.A.E. 51100 steel bearing ball to each end of a low-carbon steel rod. The techniques developed by Process Development Section to do this precise operation in volume provided an assembly which holds the overall length to within ± 0.003 in., maintains desired sphericity of the balls, and offers greater impact strength than parts made from solid stock.

plification. This is because his major responsibility is in the area of work simplification, while the product engineer is primarily concerned with product function and the production engineer is primarily concerned with production facilities. Through mutual contributions by the production engineer, the methods engineer, and the product designer, the design or material specifications can often be modified slightly without sacrificing quality but making tooling and other production factors considerably easier. While the product designer remains primarily responsible for the end product, it is in his province to consider advice from those who assume the production responsibility later.

In their work, methods men have equipped themselves with many devices for determining the optimum methods and the most suitable use of individuals at work stations. One of these is a thinking process which has been set down as the "methods engineering approach" (Table I). This is a derivative of the more familiar "engineering approach"

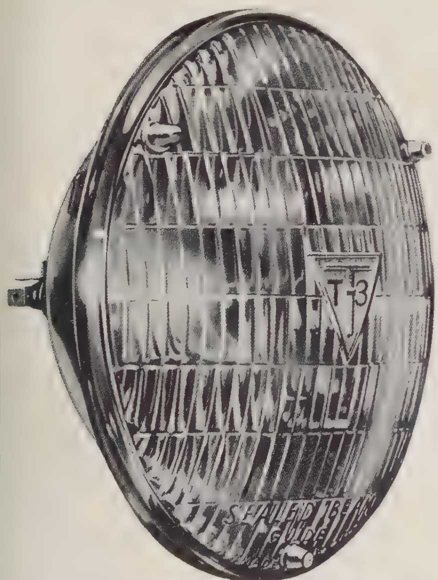


Fig. 4—Often an improvement in a product cannot be made with existing facilities. This was so in the case of the 1956 Guide Lamp T-3 automobile headlamp. To enable day or night aiming of the lamps by means of a simple accessory tool in service stations and garages, it was necessary to have each headlamp made with three glass bosses spaced on the face to describe an equilateral triangle. The faces of the bosses had to be ground so as to describe a precise perpendicular surface to the beam of the unit. A special glass-grinding machine which does this task on a production basis was designed and built by the Process Development Section. In this equipment electronic and hydraulic circuitry permit automatic aiming of the unit and control of the grinder to grind from the bosses an amount sufficient to establish the required flat plane.

and its step-by-step use results in logical analyses. Since the problems involving automatic manufacturing equipment require even greater consideration of the economics involved, this approach has proved to be an instrument to help prevent over-mechanization. The approach demands that sufficient optional methods be considered to be sure that the best within the ability of the production engineer and the methods engineer has been found. The process of this determination begins with the elements which are simplest and least costly to design and build, considered with the amount of labor to be required by these elements.

The prediction of the effectiveness or efficiency of the labor content as it would affect the operation of each machine design is one of the major services supplied by the methods engineer. His analysis may show ineffective use of labor and point to the spots where change of design would make the mechanism more effective.

The foregoing discussion has dealt with the methods engineer working to the production engineer's lead. The reverse approach also has been successful. Often the nature of the production job to be done suggests that a minimum amount of labor may be the best solution. The methods engineer then submits a suggested operator method, and the production engineer attempts to design his equipment to match the method. Jobs of this kind are usually but one step removed from complete mechanization, and with the demand for more production the unit savings resulting from further mechanical aid may be of sufficient total to justify complete mechanization.

The methods engineer exhibits and injects a way of thinking which is basic. Applied according to the "methods engineering approach," his services contribute to optimum results in production and as a corollary help to avoid the development of machinery which would be uneconomic or less suitable than other possible solutions. It is significant that the production engineer and the methods engineer, working together, succeed in improving those parts of manufacturing technology which they jointly approach. The services of other engineering specialists also enter in, and their contributions to advancement blended in with the work of production and methods engineers insure continued elevation of

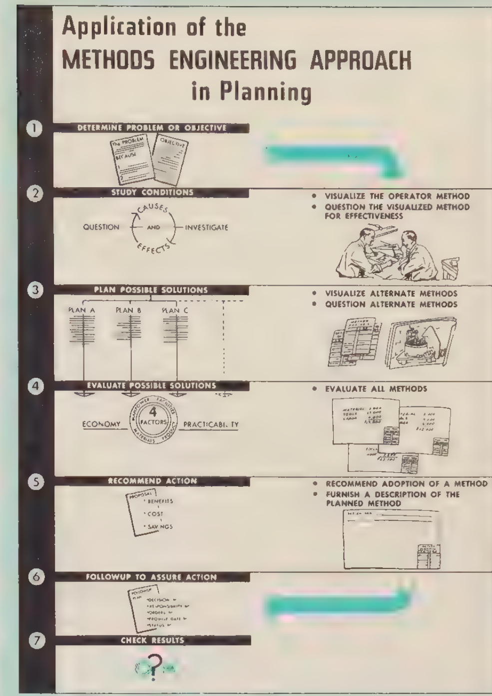


Table I—This copyrighted chart is used by methods engineers to guide their own concentration sequence when attacking any problem involving optimizing of the inter-relationship of man hours, processes or machines, and materials. Its application is useful wherever and whenever methodical thinking is an asset. It was developed by the GM Work Standards and Methods Engineering Section and GM Divisional methods engineers.

the productivity and the well-being of the men who produce.

Conclusion

Just as in the market-place the customers will continue to expect and receive improved designs of automobiles, so also will the economic factor involved continue to demand that these improvements be made possible at competitive costs. A major way to keep cost down is to gradually improve manufacturing technology. The trend in work opportunities in General Motors during the past 15 years has been toward an increased need for engineers to devote themselves to production operations. While the total employment doubled and the number of product designers quadrupled, the number of engineers in manufacturing technology increased by a factor of eight. There appears to be no leveling off of opportunities in either the product design or production advancement areas. The basic work aptitudes and educational requirements are, in general, common to both, and certainly both groups of engineers share the basic engineering objective of optimum use of materials and manpower for the elevation of man's material status.

A Manufacturing Development: the Gyrofinishing Process for Polishing Metal Surfaces

By GEORGE R. SQUIBB
and FRED T. HALL
General Motors
Manufacturing Staff

The engineer's assignment: develop a production process from a basic principle

Gyrofinishing is a process for the abrasive finishing of metal surfaces of automotive and household appliance decorative trim parts prior to electroplating. This process essentially consists of submerging the parts to be finished in a revolving mass of free abrasive material. The force of the flow of abrasive material over and about the exposed surfaces of the part produces the finishing action. Many of the metal finishing operations usually performed by conventional polishing or buffing wheels can be accomplished by the Gyrofinishing process at a savings. As a result the process has been adopted by a number of General Motors Divisions for finishing such parts as automotive door handles, emblems, and hood ornaments. The chronological development of the Gyrofinishing process, from conception to present-day applications, is an example of how engineers of the Process Development Section of the General Motors Manufacturing Staff cooperate with GM Divisions in advancing new solutions to manufacturing problems.

THE Gyrofinishing process originated from a fundamental study conducted by the Process Development Section on barrel finishing. One of the objectives of the study was to reduce the time required to process parts.

In barrel finishing the relative movement or sliding action between the parts and the abrasive media gives a finish to the parts. To acquire a desirable finish by the barrel finishing process usually requires considerable time even when optimum conditions exist, relative to barrel size and speed; size, type, and quantity of abrasive chips; ratio of parts to abrasive chips; and water level. As part of the study the axis end of a barrel was covered with a sheet of clear plastic to assist in the observation of the operating characteristics of the process (Fig. 1).

On analysis of the cascading action of the material and the parts in the barrel, the idea occurred that the long cycle operation might be reduced if the relative speed between the parts and the abrasive could be increased. It was found that, by increasing the barrel speed, centrifugal force caused the abrasive and the parts to pack against the wall of the drum. Relative movement between the parts and the abrasive media was then curtailed since they were carried around by the drum as a solid mass. It became obvious that the parts would have to be held in position to allow the revolving bed of abrasive to pass over the surface of the parts thus attaining relative movement.

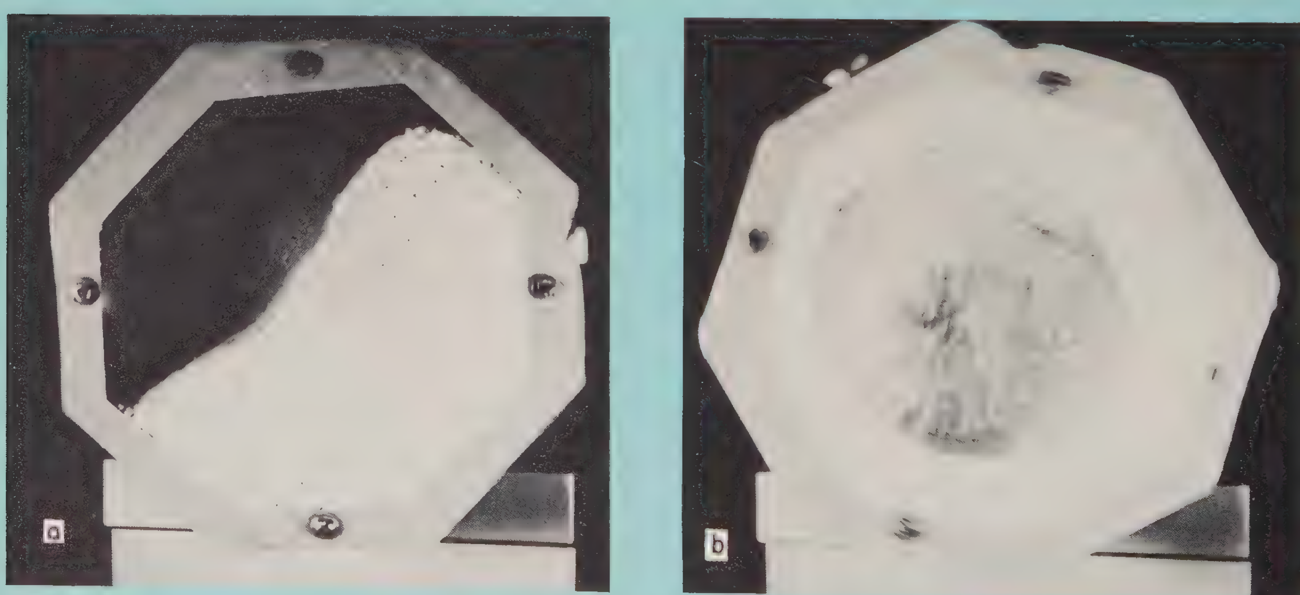


Fig. 1—A fundamental study of barrel finishing by the Process Development Section ultimately led to the Gyrofinishing process. A clear plastic cover over a loaded finishing barrel was used to enable study of the internal operating characteristics (a). It was known that the limiting factor in barrel finishing is the time necessary to do the work. If the barrel rotates too fast, there is no relative motion between the part and the abrasive mass (b). However, if the part could be held in the moving mixture and controlled from outside the barrel, the relative motion between the part and the abrasive would be greatly increased.

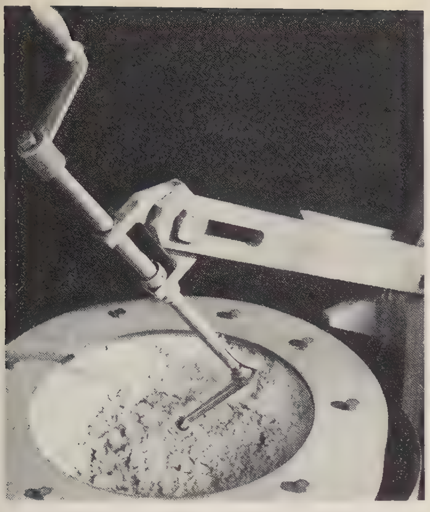


Fig. 2—The Gyrofinishing principle was first used in a small tub rotating on a vertical axis. The shaft which holds the part to be finished, in this case a window regulator handle, is mounted beside the drum. The crank handle at one end of the shaft directs the position of the part in the abrasive stream.

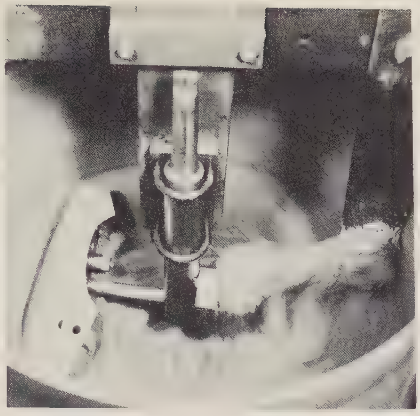


Fig. 3—A larger machine was built to study the Gyrofinishing process. By using harder abrasives it was found that steel, as well as zinc alloy material, could be finished. This view shows the flow of abrasive mixture acting on a steel bumper guard. To facilitate observation the volume of material in the drum was reduced. Normally, the part is completely covered by the abrasive. The steel "plow" at the right diverts the abrasive back into the center after it has been displaced by the part.

A project was immediately initiated to explore this idea as a possible means to improve the rate of barrel finishing. A drum, approximately two feet in diameter, was built to rotate on a vertical axis so that the abrasive mixture would be retained when spun. A shaft was mounted beside the drum in such a manner that one end which was to hold the part would be submerged in the revolving bed of abrasive. A crank handle at the opposite end of the shaft afforded means to orient the position of the part to the abrasive stream (Fig. 2). Window regulator handles were selected as the first test specimens because they were of small size, irregular in shape, and a high volume production part. It was found that the standard abrasive media used for barrel finishing (chips) had a tendency to pack and produce too harsh an action. It was necessary, therefore, to find a more suitable material. Many were tried before compounds were evolved that performed satisfactorily.

The initial experimental work disclosed that an acceptable finish could be obtained on the die cast handles within seconds instead of the hours required by barrel finishing. The method of finishing came to be known as Gyrofinishing because of the revolving action of the abrasive medium by the barrel.

Another phase of the investigation included the rotation of the part to be finished through a stationary tub of abrasive material which was varied from a dry to a wet state. A single-spindle drill press was used as the device to rotate the part while performing the tests. It was determined that the process time was more than tripled by revolving the part through the abrasive in comparison with revolving the abrasive mass about the part. The increase in process time was attributed to the reduction of the density of abrasive material. When the drum is revolved, the centrifugal effect increases the density of the Gyrofinishing media. It was learned during this phase of the investigation that the Ternstedt Division of General Motors Corporation had perfected the technique of passing parts through a stationary tub of abrasive mixture to a point where it was being utilized to finish die-cast automotive door handles for production. This method of finishing was called the "Fadgenizing Process."

As part of the study the General

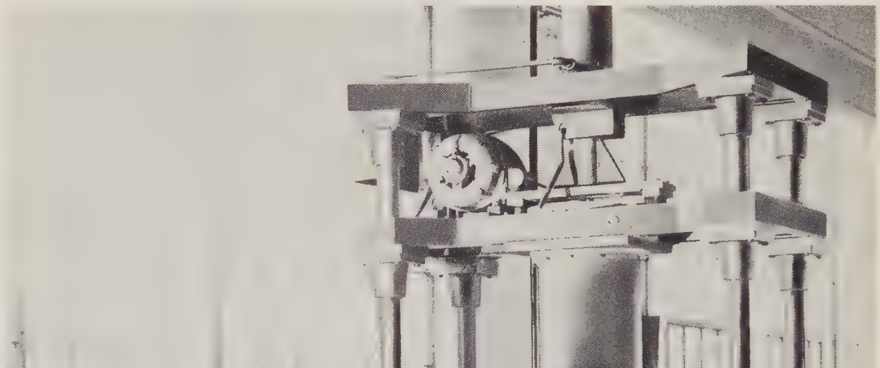


Fig. 4—This experimental Single Station Vertical Gyrofinisher consists of a vertical drum containing the abrasive mixtures with an air cylinder attached to the machine head to lower parts into the abrasive. Spindles mounted on the geared head at 90° to the vertical drum can be revolved clockwise or counter-clockwise. Bolted to the spindles are fixtures to hold the parts for finishing.

Motors Patent Section was requested to check on the clearance of free abrasive finishing to avoid possible infringement. It was found that the basic principle of the Gyrofinishing process had been patented in the nineteenth century and was no longer in force. The primary application of the process as patented was adapted to the finishing of openings in scissor handles. Information regarding the abrasive materials and technique used in free abrasive finishing was found to be limited. Therefore, work was continued in the direction of learning more about the characteristics and possible applications of the Gyrofinishing process.

Applications of the Gyrofinishing Process

To facilitate further study of Gyrofinishing a larger machine was built to accommodate a greater variety of parts. With this larger machine it was found that steel as well as zinc-alloy material could be Gyrofinished by using harder and more aggressive abrasives. Automotive bumper guards and grille parts were polished successfully in this type of machine (Fig. 3). Other materials, such as aluminum, brass, and stainless steel, also were polished successfully by Gyrofinishing.

The successful application of the process in finishing larger size parts led to the design of a still larger, more versatile machine (Fig. 4). This machine consisted of a vertically positioned drum to hold the abrasive mixtures. Parts to be finished were lowered into the abrasive mixture by means of an air cylinder attached to the machine head. The geared head contained four spindles mounted at 90° to the drum's vertical axis. The spindles could be revolved in clockwise or counterclockwise directions by a drive mounted on top of the platen which supported the geared head. The platen was guided by four posts as it was raised or lowered by the manual air control valve. Fixtures to hold parts for processing were bolted to the face of the spindles.

The machine was designated as a Single Station Vertical Gyrofinisher. The basic unit is currently used primarily for laboratory work to develop better abrasive mixtures and to run sample parts for various GM Divisions to determine possible application of the process. Such data as quality of finish, amount of area covered in processing, process time, and type of abrasive material are ascertained by running sample parts. If the finishing of parts by means of the Gyrofinishing process is deemed practical, parts are submitted to those concerned for evaluation. If the finish is acceptable and interest is shown by the Division, a proposal for equipment requirements and attendant cost is submitted.

Fig. 5—Since irregular shaped parts tend to tear, deteriorate, and reduce buff life, the Gyrofinishing process shows its greatest material savings on these finishing operations. Shown above is a selection of typical parts which have been processed in Gyrofinishing machines before electroplating.

Characteristics of Gyrofinishing

In comparison with conventional buffing or polishing operations, a Gyrofinished surface on zinc-base alloy die-cast parts is a shade lower in color than a buffed surface. Directional or flow lines on the surface of the Gyrofinished part may be more pronounced than obtained by ordinary buffing. With the standard copper-nickel-chrome plating cycle the fine abrasive scratches or flow lines are not in evidence.

It has been determined that the Gyrofinishing process offers a greater unit cost savings over buffing where the part is applicable with respect to size, shape, and quantity. Odd shaped decorative parts have a tendency to tear, deteriorate, or otherwise reduce buff life, and on such parts the Gyrofinishing process shows its greatest savings (Fig. 5). Normally, 0.0005 in. to 0.001 in.-thickness of metal is removed from the surface of die-cast parts which have been Gyrofinished for 60 seconds to 70 seconds. Uniformity of metal removal is regulated by changing the position of the parts with respect to the flow of abrasive mixture in order to avoid loss of detail of design. Flow of the abrasive mixture must be obtained over the area to be finished. Small holes and depressions generally cannot be finished by Gyrofinishing. The same limitation, of course, applies to buffing.

Very often both sides of a part can be Gyrofinished, while in buffing the part must be turned over to buff the underside. A typical example of such parts are automotive hood ornaments. Greater efficiency in cutting, however, is obtained on the surface of the part exposed nearest the periphery of the drum. The wedging action of abrasive material between the drum wall and the parts creates additional pressure and improves the rate of cut. Because work is being accomplished by the action of the abrasive, vapor is given off during the operation as a result of the heat being generated. The operating temperature of the abrasive mixture may range up to 160° F to 180° F. The loss of vapor must be replaced by the addition of water during processing. The control of water content is important from the standpoint of obtaining maximum operating efficiency.

Abrasive Mixtures

Many abrasive mixtures have been tried since the initial test work on the Gyrofinishing process began. The composition of the mixtures most widely used in production today is as follows:

Maizo (ground corn cob)—40 to 60 per cent by weight of the dry mixture

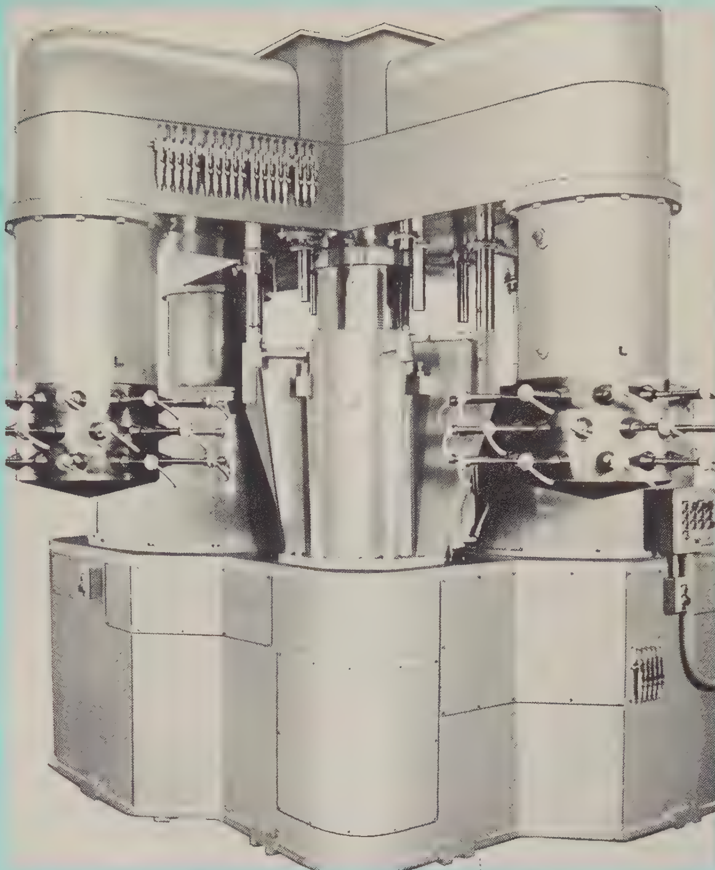
Liquid Buffing Composition—60 to 40 per cent by weight of the dry mixture

Moisture—water 20 to 30 per cent by weight of the total mixture.

Generally, commercially available liquid tripoli compound is used to finish zinc alloy die castings and liquid stainless (aluminum oxide) is used for steel parts. Not all compounds available are satisfactory for Gyrofinishing purposes. Compounds are selected on the basis of performance, cost, and cleaning in the plating cycle. Several other abrasive compositions are in use, such as lime and white coloring compounds, to obtain variations in cut and color properties. The maizo or ground corn cob constituent of the Gyrofinishing mixture is used as the backup or carrier for the abrasive particles. The abrasive grit is held to the maizo by the grease binders used in the liquid buffing compositions. Properly graded leather meal or sawdust may be substituted for the maizo abrasive carrier. In a sense, the Gyrofinishing abrasive mixture consists of a multitude of $\frac{1}{16}$-in. diameter, or less, ball-shaped particles. The best speed at which the particles of abrasive should flow past the part has been found to be between 1,500 surface feet per minute (sfpm) and 1,800 sfpm.

Vertical Gyrofinishing Machine

The first Gyrofinishing machine for the production finishing of parts was a multiple station machine designed and built for one of the GM car manufacturing Divisions. Steel bumper guards and grille bars were polished with this machine. The machine had a load-unload station, two polishing drums, and a wash station to collect surplus abrasive. The machine was a maypole design with four, four-spindle processing heads. In operation, the spider superstructure carrying the machine heads would rise, index, and lower into place automatically. These movements were all accomplished hydraulically. The abrasive-carrying drums were rotated in opposite directions to achieve optimum part finish.



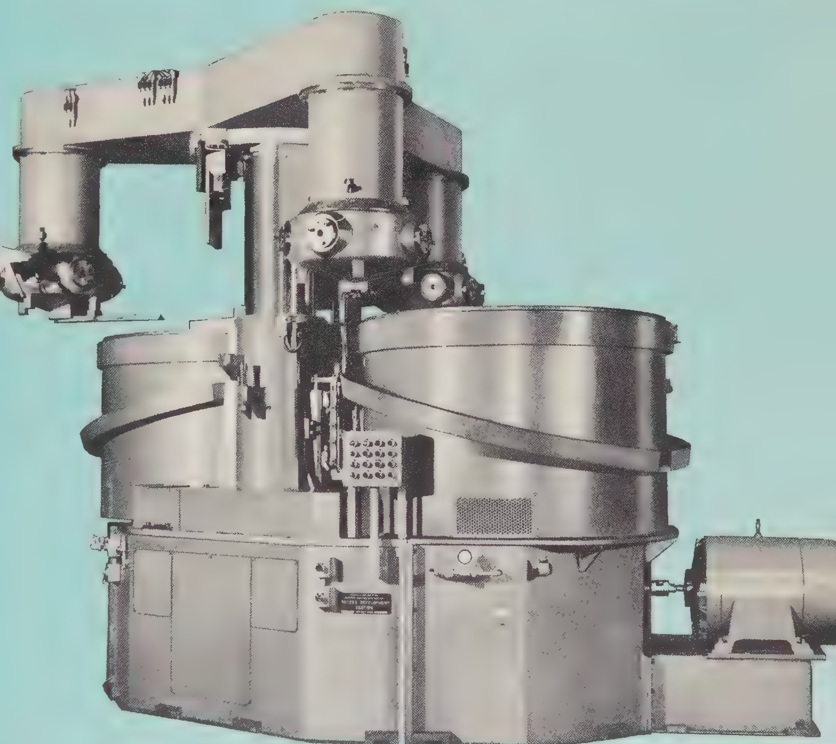


Fig. 6—One of the earlier Gyrofinishing machines built was a multiple station machine designed for finishing automotive interior door hardware (top). A later machine was the Three Station Gyrofinisher (bottom) which shows the processing heads in the raised position and illustrates the feathering spindles and abrasive collection troughs.

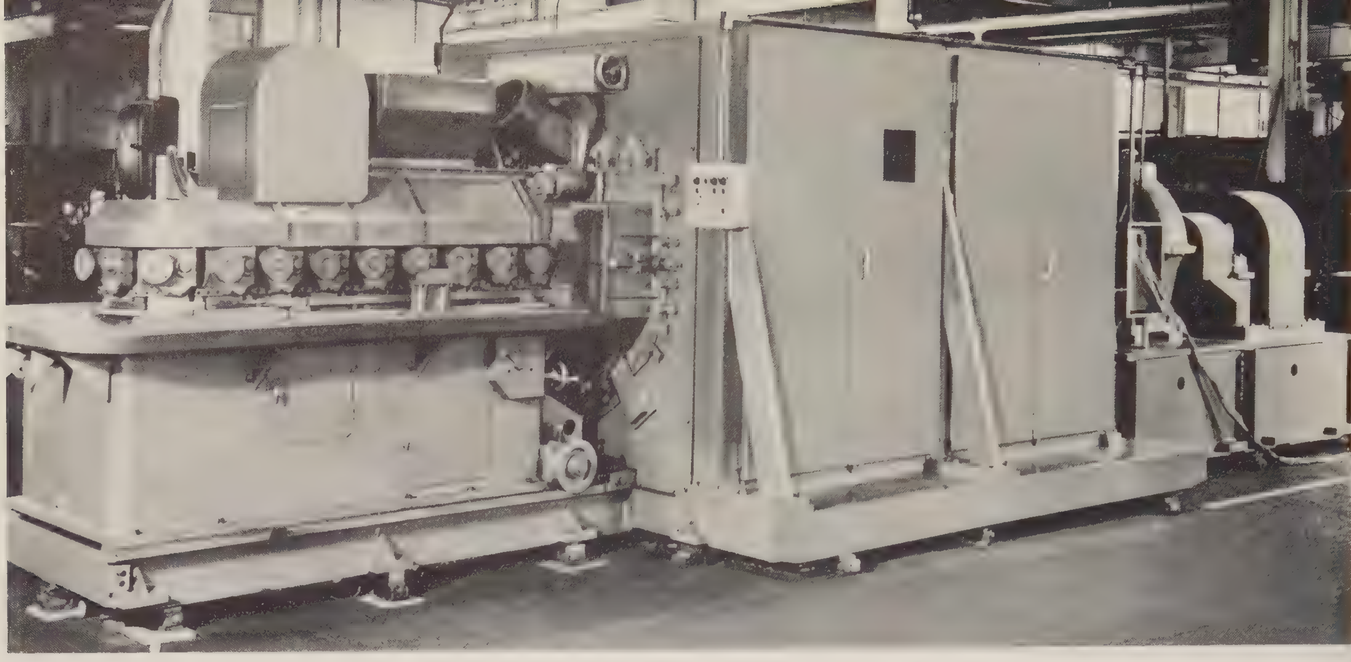


Fig. 7—This horizontal-type Gyrofinishing machine was developed to eliminate the loss of process time that occurs during the indexing of spindle heads from drum to drum in the vertical-type machine. Parts to be finished are carried into the open end of the drum by a conveyor and are rotated within the drum by means of cams. A screw conveyor also is provided to convey, load, and replenish the abrasive material into the drum while it is in motion.

The second Gyrofinishing machine was designed and built for General Motors of Canada, Limited to polish steel parts. This machine was a single station vertical-type design for Gyrofinishing parts having lower production schedules.

Multiple station machines also were designed and built for GM of Canada, Limited and Chevrolet Motor, Ternstedt, and Brown-Lipe-Chapin Divisions (Fig. 6).

Horizontal-Type Gyrofinishing Machine

An inherent disadvantage in the design of the vertical type Gyrofinishing machine is the loss of process time that occurs during the indexing of the spindle heads from drum to drum. To overcome this problem a horizontal-type Gyrofinishing machine was developed (Fig. 7). With this design the axis of the drum is positioned in a horizontal plane to provide a more uniform depth of abrasive mixture for processing. The parts to be finished are carried into the single open end of the drum by a continuously operating conveyor supported by a cantilever beam. While in the drum, the parts are rotated or feathered by means of cams. Parts are loaded and unloaded outside the drum while the conveyor is in motion.

The spindles on which the parts are mounted do not rotate in the unload-load stations but can be cammed to position the parts to assist in unloading and loading. Many parts lend themselves to automatic unloading. A screw conveyor is provided to facilitate loading and replenishing abrasive material into the drum while it is in motion. The screw conveyor is equipped with suitable paddles to pre-mix the abrasive material while being conveyed into the drum. Spent abrasive material is removed from the drum by means of a blade which is raised to deflect the flow of abrasive into the screw conveyor which, operating in reverse direction, carries the material out of the drum.

The cantilever, horizontal machine has been under continued developmental work to further improve its design and to reduce the processing time requirements.

The horizontal Gyrofinisher is essentially a mechanical machine. Unlike the vertical designs, the machines have no hydraulic components. The electrical circuit is relatively simple. The electrical components consist of limit switches for operator safety, drum drive, parts conveyor drive, screw-feeder drive motors, electrical panel, and push button stations. Consequently, maintenance is kept to a minimum.

Conclusion

The development of the Gyrofinishing process illustrates how engineers—working in specialized facilities for manufacturing development—concentrate on the uncommon problems in manufacturing to bring about improved processes, reduced costs, and increased value for the user.

A fundamental study of methods for finishing metal parts conducted by the Process Development Section ultimately led to new machines and applications of a successful process. It was found that the principles of barrel finishing could be improved by passing the abrasive at high speeds around a metal part held in a stationary position. The reduction in processing time to achieve a satisfactory finish suggested the application of the process to the finishing operation required prior to electroplating.

The Gyrofinishing process was found to have advantages when applied to particular types of parts such as those parts requiring finish on both sides and parts having irregular or pointed shapes which would rapidly wear out buffing wheels. Several types of Gyrofinishing machines have been built and placed in operation in various plants of General Motors. Additional benefits gained from the use of Gyrofinishing machines as compared to automatic buffing machines of the straight-line type were a savings in floor space and reduced down-time when changing parts to be processed.

With continued developmental work numerous improvements have been made, including the development of a horizontal-barrel type Gyrofinishing machine fed by a continuous conveyor which overcomes some of the disadvantages of the vertical-barrel types for certain applications.

Unique Architectural Elements of the GM Technical Center

By FREDERICK G. TYKLE
and ERVINE E. KLEIN
General Motors
Manufacturing Staff

Curved shapes relieve repetitious severity of vertical-horizontal details, but require special engineering care

Credits

Eero Saarinen & Associates
architect

Smith, Hinchman & Grylls, Inc.
architect-engineer

Bryant & Detwiler Co.
general contractor

Bolt, Beranek, & Newman
consultants on acoustics

Chicago Bridge & Iron Co.
engineers-fabricators-erectors
auditorium dome and water tank

One test of good architecture is the ability to obtain design continuity. In multi-building projects there is temptation to copy or design and detail all structures alike. Deviation from this easy approach requires great skill and care to achieve composition that looks ana fits as a whole idea. The Technical Center structures are, generally, horizontal buildings, incorporating vertical detailing. Different activities are housed in separate units. Each unit, or building, is cubic shaped, and great care was taken to avoid the usual projections, the "ups and downs," the "ins and outs," generally necessary to house lobbies, penthouses, cranebays, monitors, cooling towers, and cupolas. When such projections were necessary, each was treated as a separate cube rather than as an extension of exterior wall; therefore, the site-planning became a problem of arranging the "building blocks." The crispness of this cubic architecture and delicate, vertical detailing was relieved by strategic introduction of curved shapes as architectural features. The curved shape, represented by a selection of Technical Center features, posed interesting challenges to the architect-engineers and to the erectors, who in the final anaylsis had the job of executing the design intent.

IN THE construction industry one of the results of the vast economic expansion since World War II has been the increased activity in the field of industrial architecture. Large volumes of new construction have been required. Yet, just as in other industrial enterprises, the speed with which a new product was needed—buildings in this case—did not waive the desirability of improving the product.

General Motors has now completed its Technical Center, and the achievement of both a new and an improved concept of industrial architecture, one of the objectives since the beginning of the project, has been attained. An understanding of this concept can be gained from the illustrations and discussion of the various Technical Center Staff activities and facilities given elsewhere in this issue. As a further aid in understanding this concept and also to stimulate the architectural imagination, it is interesting to examine some of the unique architectural elements of the Technical Center. The discussion of these selected features emphasizes the relation of shape to engineering and construction considerations rather than the relation of shape to the aesthetics of form, mass, and composition.

The Styling Auditorium—Circular Plan, Domed Roof and Ceiling

The Styling Auditorium was built in a circular plan with a domed roof and ceiling (Fig. 1)—an idea derived from the pressure vessel industry. One of the primary uses of the Auditorium is for indoor display of automobiles which requires totally diffused light to eliminate all reflections on the curved surfaces of automobiles. The primary engineering problems were four-fold: structural, acoustical, lighting, and ventilation.

Structural Problems

The thin, $\frac{3}{8}$-in. steel plate dome was designed to be a self-supporting, struc-

Fig. 1—The Styling Auditorium illustrates the relationship between the vertical-horizontal lines of Technical Center buildings and the curved shape as represented by the dome of the Auditorium. The automobiles shown illustrate the scale of the buildings which were scaled to the automobile rather than to the person.

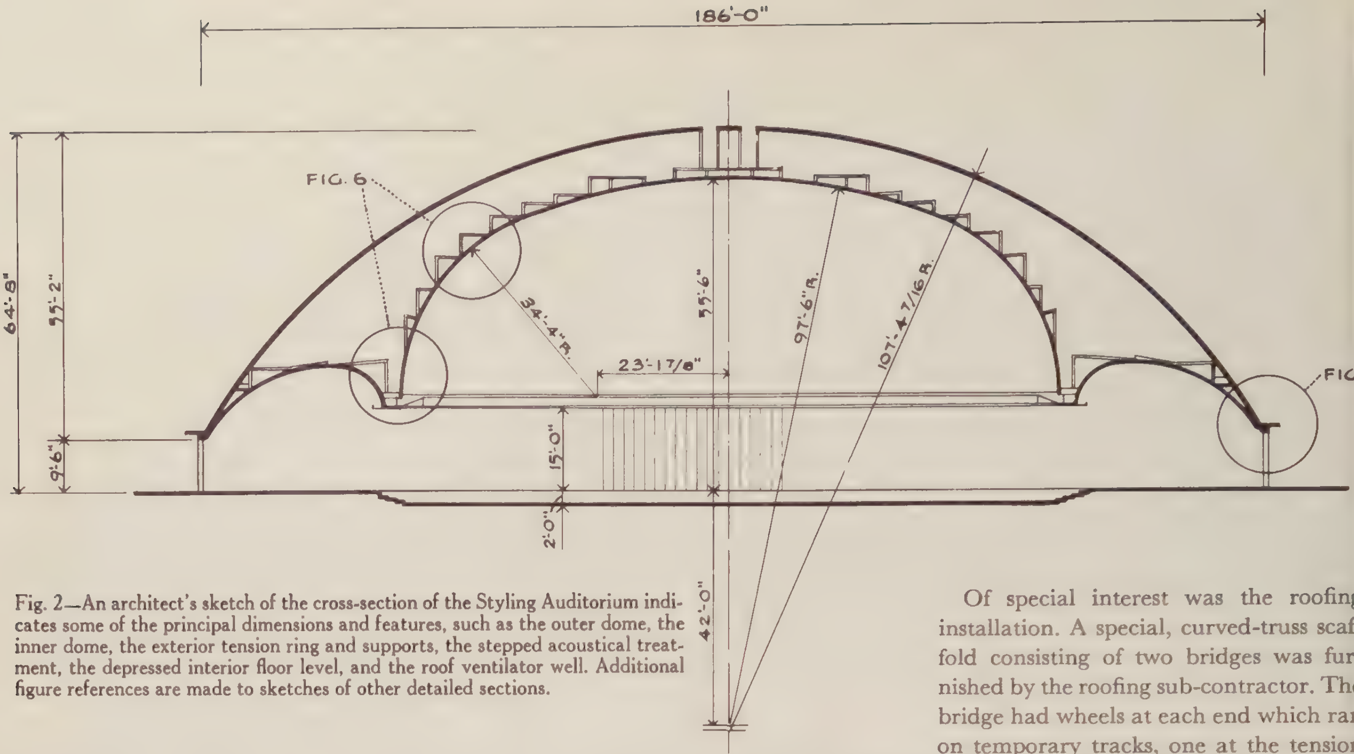


Fig. 2—An architect's sketch of the cross-section of the Styling Auditorium indicates some of the principal dimensions and features, such as the outer dome, the inner dome, the exterior tension ring and supports, the stepped acoustical treatment, the depressed interior floor level, and the roof ventilator well. Additional figure references are made to sketches of other detailed sections.

tural shell, 65 ft high and spanning 186 ft—the first such application in a building. The dome also had to be capable of supporting an acoustical shell forming the inner dome or interior ceiling (Fig. 2).

The outer dome was designed to be supported on a circumferential channel tension ring, 9 ft 6 in. above the ground level, supported on columns. The circumferential channel tension ring (Fig. 3) had a structural function as well as being an architectural design detail.

The erection of the dome was a predetermined, step-by-step procedure. After completing the reinforced concrete sub-structure and first floor slab, a central tower of scaffolding was erected, supplemented by gin-poles, jib-booms, and shores to facilitate the placing of the pie-shaped, two-way curved plates. Next, exterior columns and the exposed facia tension ring were erected. Initially the ring was tack-welded, then continuously welded when the circle was complete.

A top roof-ventilator well was then placed on top of the scaffold tower, and the top horizontal row of plates was erected (Fig. 4). Following this step, plates were erected from the tension ring up, in the plane of the horizontal curve. After several sections were in place, it was possible to put up double plate sections, and later it was possible to put up triple plate sections thereby reducing the time and cost of welding. These pre-formed plates were welded together on the ground in prefabricated cradles. Welding on the dome was a progressive operation with each horizontal row being in place prior to tack welding. After all plates were tack-welded, the entire dome was continuously welded.

Of special interest was the roofing installation. A special, curved-truss scaffold consisting of two bridges was furnished by the roofing sub-contractor. The bridge had wheels at each end which ran on temporary tracks, one at the tension ring, the other at an upright angle two-thirds of the way up the dome (Fig. 5).

Acoustical Problems

The acoustical problem presented by the circular plan and curved ceiling of

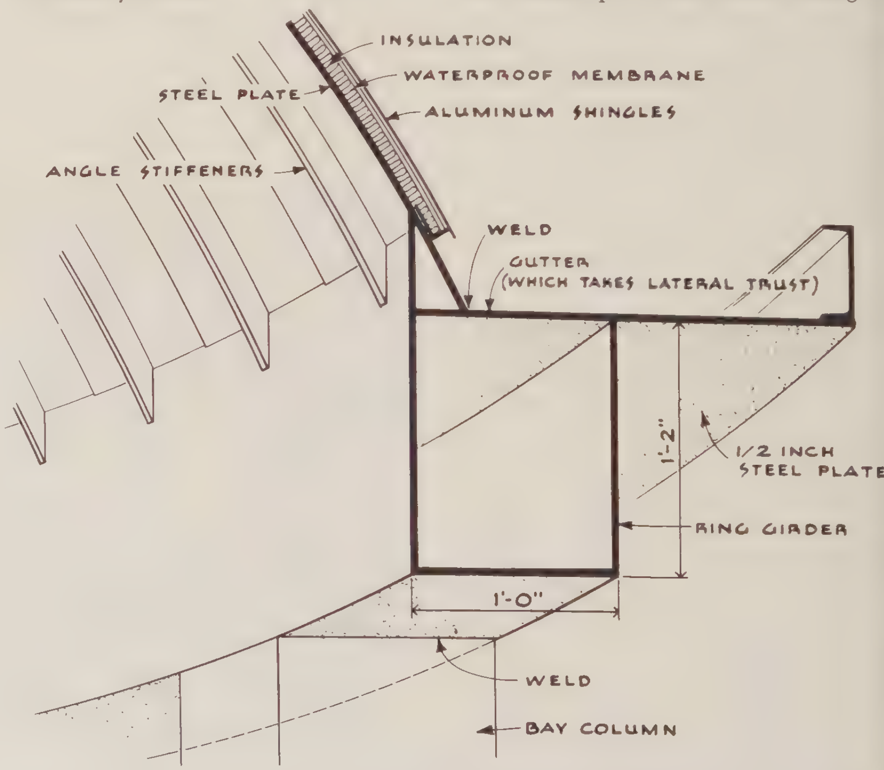
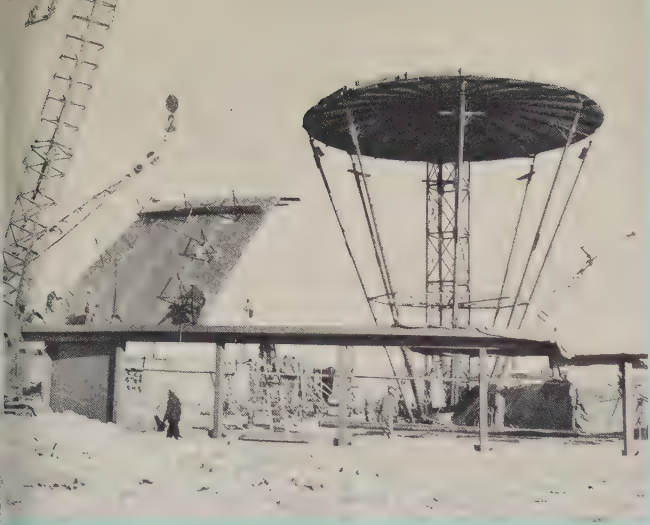


Fig.3—An architect's sketch illustrates the detail of the Auditorium facia tension ring at the circumference of the outer dome. As is typical with many of the Technical Center buildings, the structural steel has continuously welded connections, and, as shown here, the steel remains exposed as a design feature. The ⅜-in. steel plate dome is weather tight; however, it is covered with weathering aluminum shingles and insulation for economy in heating and air conditioning.



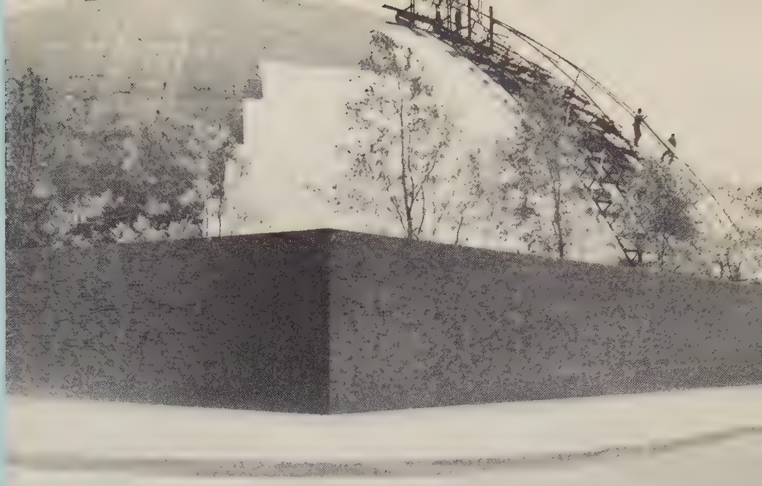


Fig. 4—The early steps in the erection of the Styling dome were to install a central scaffolding tower and the exterior tension ring and supports. One row of two-way curved plates was installed at the top, and the remainder of the plates were installed beginning at the tension ring. This structural steel erection took place during the winter months; however, very little error was encountered due to temperature changes, in spite of close tolerances.

Fig. 5—The Styling Auditorium roofing installation was accomplished using two curved scaffolds which were designed and furnished by the roofing sub-contractor. The shingles are trapazoidal in shape, nominally 5 ft by 10 ft, with the top slightly narrower than the bottom.

the Auditorium represents the exact opposite of the ideal conditions for proper acoustical conditioning. Without proper acoustical engineering in this type of construction, for example, one may whisper at the circular exterior wall and have the sound returned 360°. The curved ceiling and circular plan, however, are exactly right for light diffusion and for displaying automobiles.

For ceiling material acoustical plaster was first considered; however, due to the large, unbroken area involved (approximately 160,000 sq ft), it was felt that this material would set up too fast to avoid a patched appearance. Secondly, if any defect appeared later, it would be difficult to blend in a patch. Finally, the consulting acoustical engineer advised that acoustical plaster would not provide the required sound absorption in this application.

Another method considered was the use of standard, perforated metal ceiling pans. It was felt, however, that the two-way curve of the domed ceiling would not be a sympathetic shape for small, square, flat tiles.

The final solution was the use of pie-shaped wedges (⅛-in. sheets, 15 per cent perforated) with terraced layers of acoustical pads in the above-ceiling space (Fig. 6). When the large ceiling tiles were bolted to arched supporting ribs, the tiles were drawn up automatically into the desired two-way curve. The irregularity of surface of the terraced layers of acoustical pads above the ceiling eliminated focusing reverberation or reflection of sound. As in lighting coverage, acoustic diffusion must be attained to avoid "hot-spots," or concentrations of sound. To supplement the ceiling treatment the inner circular wall also was acoustically treated. The masonry wall was lined with a three-inch blanket of insulating material and covered with an aluminum screening, which is visible as a finished wall surface between decorative, vertical, extruded aluminum slats. The vertical slats create a desirable, irregular surface, as well as providing depth and additional mass. The projection also provides a shadow and louvered effect. The aluminum screening is a refined variation of the conventional industrial installations of sound-absorbing material covered with wire cloth.

Lighting Problems

The entire Auditorium inner dome is essentially a single light fixture reflector approximately 115 ft in diameter at its base. The design problem was to obtain totally diffused light so as to eliminate all reflections on the gleaming, curved surfaces of automobiles on display. Lighting requirements were 350 to 400 foot candles on the ceiling and 120 foot candles on the floor. These requirements were met by installing lamps within the periphery ceiling light cove. There are 140 1,000-watt incandescent lamps alternating positions with 140 500-watt mercury vapor lamps (Fig. 6). This is the only known installation of mercury vapor lights with dimmer control. A total of 225 kilowatts of light are used.

Ventilation Problems

The cove lights generated heat amounting to approximately 768,000 Btu (3,413 Btu/kw $\times$ 225 kw = 767,925 Btu). This intense heat was required to be exhausted without grilles in the ceiling dome—the ceiling being the large light fixture reflector. At first, the designers considered exhausting air through ducts from ports spaced around the cove. However, the above-ceiling catwalks, the web of ceiling suspension members, and the tiers of acoustical steps made this approach impractical. The final solution was to use the above-ceiling space as an exhaust air plenum, placing a central roof exhaust unit in a well at the top of the dome. This design also complied with the architect's requirement that there be no projection on the Auditorium dome.

The Spiral Floating Stair

In keeping with the emphasis on technological progress, a unique spiral, suspended stair was selected to become a large-scale sculptural and ornamental feature of the Research Staff Administration Building lobby. Although the spiraling treads of green Norwegian granite (butterfly pattern) weigh 1,500 lb each, they seem to float upward in space. The treads are held from above and below by ⅜-in. stainless steel suspension rods fastened to special, machined fittings (Fig. 7). At the outer circum-

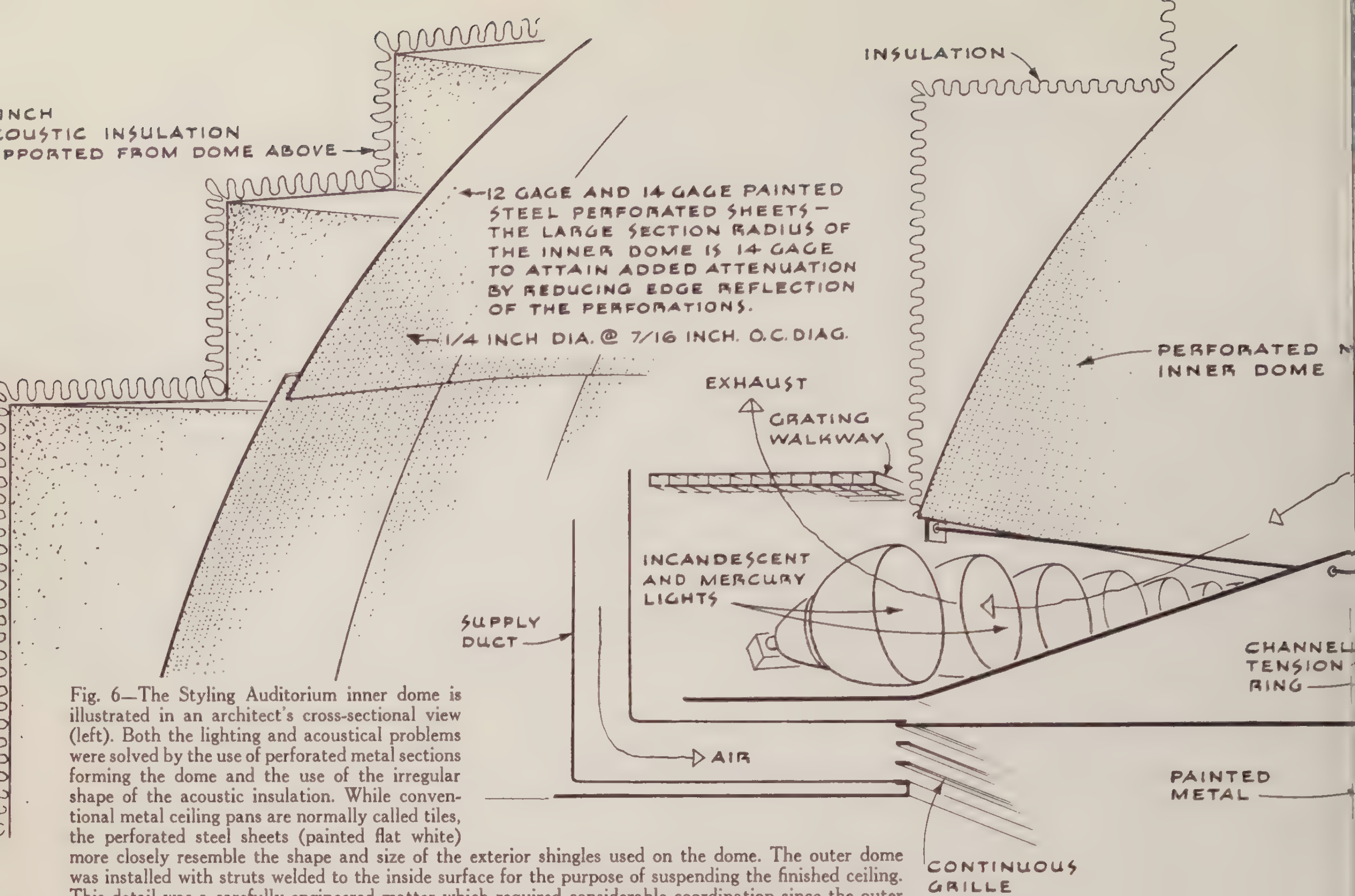


Fig. 6—The Styling Auditorium inner dome is illustrated in an architect's cross-sectional view (left). Both the lighting and acoustical problems were solved by the use of perforated metal sections forming the dome and the use of the irregular shape of the acoustic insulation. While conventional metal ceiling pans are normally called tiles, the perforated steel sheets (painted flat white) more closely resemble the shape and size of the exterior shingles used on the dome. The outer dome was installed with struts welded to the inside surface for the purpose of suspending the finished ceiling. This detail was a carefully engineered matter which required considerable coordination since the outer dome and ceiling were furnished and installed by separate sub-contractors and different trades. Lighting and ventilation details are illustrated in an architect's sketch of the ceiling light cove in the Styling Auditorium (right). The heated air resulting from the lighting load is exhausted through an invisible grating by the fan located in the roof ventilator well. The face of the light source is on an approximate 58-ft radius in the horizontal plane from the center of the Auditorium. The light source is approximately 18 ft above the depressed floor level of the Auditorium.

ference of the stair treads, the rods suspend each granite slab from a stainless steel billet which serves as a shear-block. Each rod extends upward from the billet to the second floor well railing and thence downward from a swivel fitting to a fastening at the second floor level.

At the inner circumference of the stair treads the tension rods extend from a swivel fitting at the shear-block both upward and downward to terminal collector plates, one at the second floor ceiling, one at the first floor level. The rods to the floor terminal provide lateral stability by creating a compression ring of the tension rods which work like wire wheel spokes favored for some types of automobiles. The suspension rods to the ceiling terminal create a unique, geometric, revolving "bird-cage" effect.

Erection of the spiral stair was begun by installing the floor and ceiling collector plates which were very accurately located and plumbed. A wood, trestle-like, crib-work which would follow the spiral of the stair was then built by skilled "form-work" carpenters. The cribbing was held at one inch under each tread. The stone slabs were set by instrument from the bottom step up, with wedge shims placed between the top of the cribbing and the bottom of the treads to achieve the proper level, and billets were secured progressively. Then the fittings and rods were assembled into place and adjusted with a torque wrench. The rods were put into place from the top steps down. Each rod was pulled up tight, lifting just enough to pull each slab free, then slackening off so that each stone rested exactly on the cribbing at proper elevation. At this stage the one-inch shims were removed, a loading test was performed for measuring deflection, and the tension in each rod was accurately measured with a tuning fork. Following minor adjustments, the handrail was placed, and the cribbing was removed. After several months of use no further readjustment has been necessary.

The Spinal-Beam Stair

Located opposite a two-story, modular glass wall, a spinal-beam stair creates a floating-form in silhouette from within and is sharply visible from without (Fig. 8). This stair is in the lobby of the Technical Center Service Section Administration Building. Again, as in the case of the spiral stair, this stair is kept free of enclosing walls to create a feeling of space. The spinal-beam itself is composed of one-inch steel plates, welded and ground to an exacting tolerance (Fig. 9).

Treads are one-inch thick travertine slabs, set in grout, on welded steel grating. The grating, in turn, is also set in grout within a flanged steel pan, the basic tread. The grating acts as the structural member which cantilevers equidistant from the spinal beam. The pan rests on, and is bracketed to, the beam by means of a welded seat angle, 10 in. wide. The plane-of-weakness joints are located at the shear-points in the travertine treads.

—Several architectural details of the spiral
n the lobby of the Research Staff Administration
ng are illustrated in this sketch. To keep pace
the emphasis on technological progress, this
was selected to become a large-scale sculptural
rnamental feature of the lobby. The delicate
ng and precision machining to exacting tolerances
closely to the building itself and the the industrial
on therein.

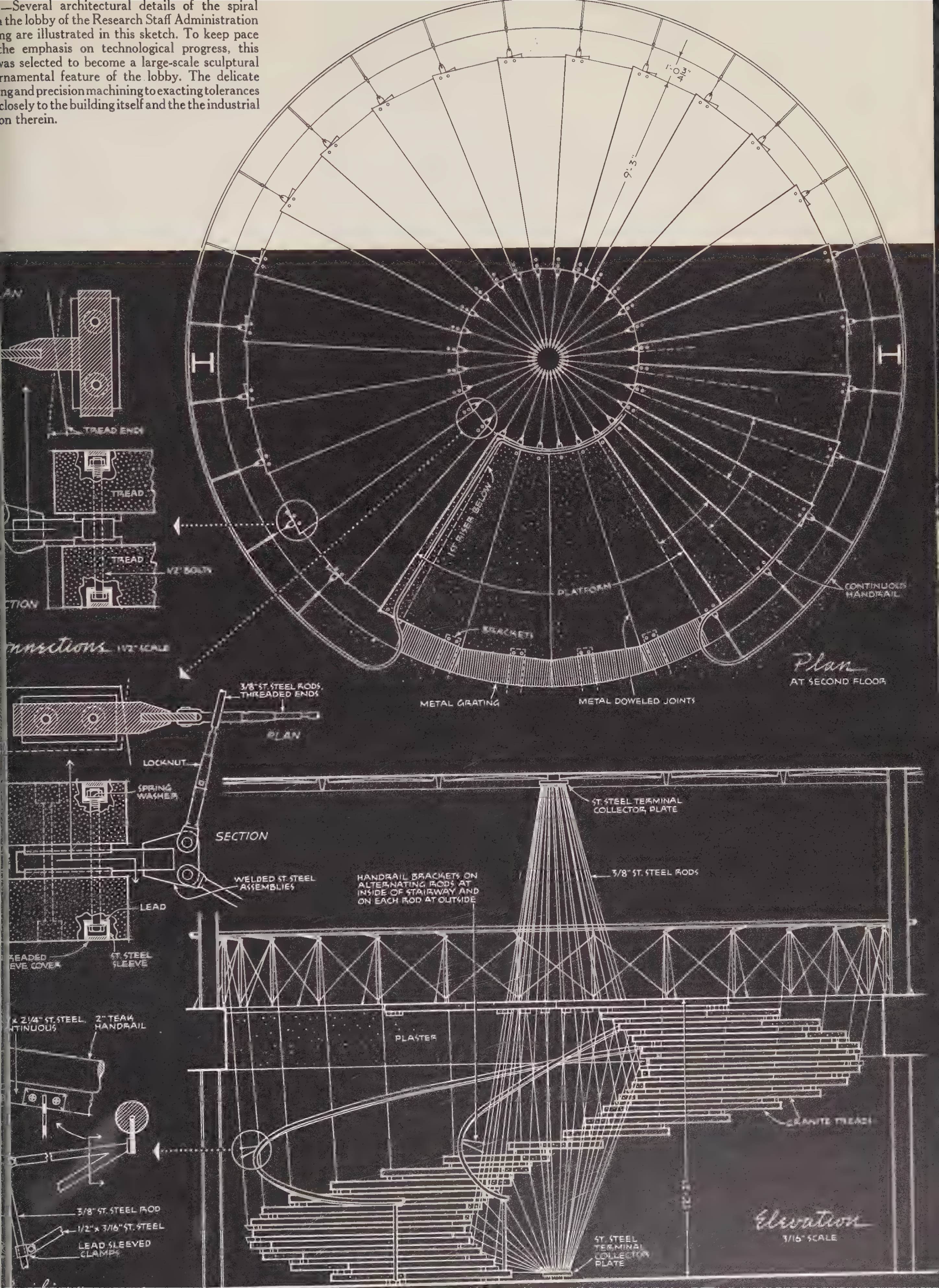


Fig. 8—The tapering lines of the spinal-beam stair are viewed from the lobby of the Technical Center Service Section Administration Building looking through an exterior glass wall. Since the exposed structure is a design feature, careful workmanship and erection were of utmost importance. Aside from the unusual character of the stair, no special engineering problems were involved.

The Canopy and Single-Column Support

Consistency of detailing, religiously followed, is expressed in the relationship of the stair steel work and a single, star-sectioned, tapering column which supports the up-swept canopy of the Service Section Administration Building (Fig. 10). The architects first specified this column to be stainless steel; however, the construction schedule occurred during a period when nickel-bearing stainless was not available. The carbon-steel column now seems to fit the surroundings, and, in the final analysis, good design should not be dependent on deluxe materials. It is of interest that this single-column support was presented by the project structural engineer as a problem in the Michigan State Board Examination for Registration of Architects and Civil Engineers (1954). As a matter of interest, this examination problem is presented in the appendix to this paper.

The Elevated, Stainless-Clad, Water Tank

The water tower at the Technical Center "rides" on the underground water main to provide supplemental head for fire protection emergencies. A true ellipsoid, the water tower is 138 ft high and is constructed of type 302 stainless-clad plate. It has a capacity of 250,000 gal at 60 lb pressure. One leg contains a stairway for service access, one leg is for water transit, and the third leg completes the triangulation of support. The tower rises out of the water, at the northeast corner of the artificial lake. As a sidelight of special interest, experience has proven the lake to be an economical form of landscaping, in addition to forming a pleasant setting for the buildings.

At the project's start the architects mentioned that a water tank would be necessary and that, since such tanks are usually ugly structures, elevated tanks are generally located in the background. In this instance, it was felt that the tank could be brought out in the open and assigned a place of prominence as a symbol and a design feature. Because the subject matter is water, the rightful place seemed near or in the lake, and, as a practical consideration, this would be quite near the center of the property.

Summary

At the inception of the Technical Center project a team was formed to execute the proposed undertaking. As members of the team the four principal participants were: architect, engineer, contractor, and owner.

- *Architect*—Design responsibility was delegated to the architect for imagination and skill to develop and solve the owner's requirements and needs, both immediate and future. Design control was a continuous discipline until the project was completed.
- *Engineer*—Technical specialists were needed to supplement the architect's services in order to properly complement the design and planning by coordinated engineering solutions. These solutions had to make the design "work" while still complying with the owner's requirements.
- *Contractor*—Construction management is always required for the efficient and correct sequence of erection. Superintendents, foremen, and engineers must execute the plans and specifications into the preconceived structures and facilities. Simultaneously, many administrative experts are required for the business matters of construction.
- *Owner*—Due to the scope and importance of this project, GM management recognized the need for active owner participation as a major role. Project management and control was principally executed bv two groups of GM employes.

  One group was activated to become the project housekeeping and administrative "landlord," as well as to be responsible for project budgeting, cost control, and establishment of basic owner requirements. Because buildings and facilities were completed and occupied in progressive stages, it was necessary for this group to simultaneously assume their primary landlord function, as well as to keep pace with project planning and construction.

  The second group was assembled as a field force for construction supervision. In addition to supervision, related duties of architectural liaison, construction accounting, timekeeping, estimating, shop inspection, expediting, and material warehousing were performed by a completely staffed organization.

  To supplement these two project forces many other GM personnel and Divisions were active in owner

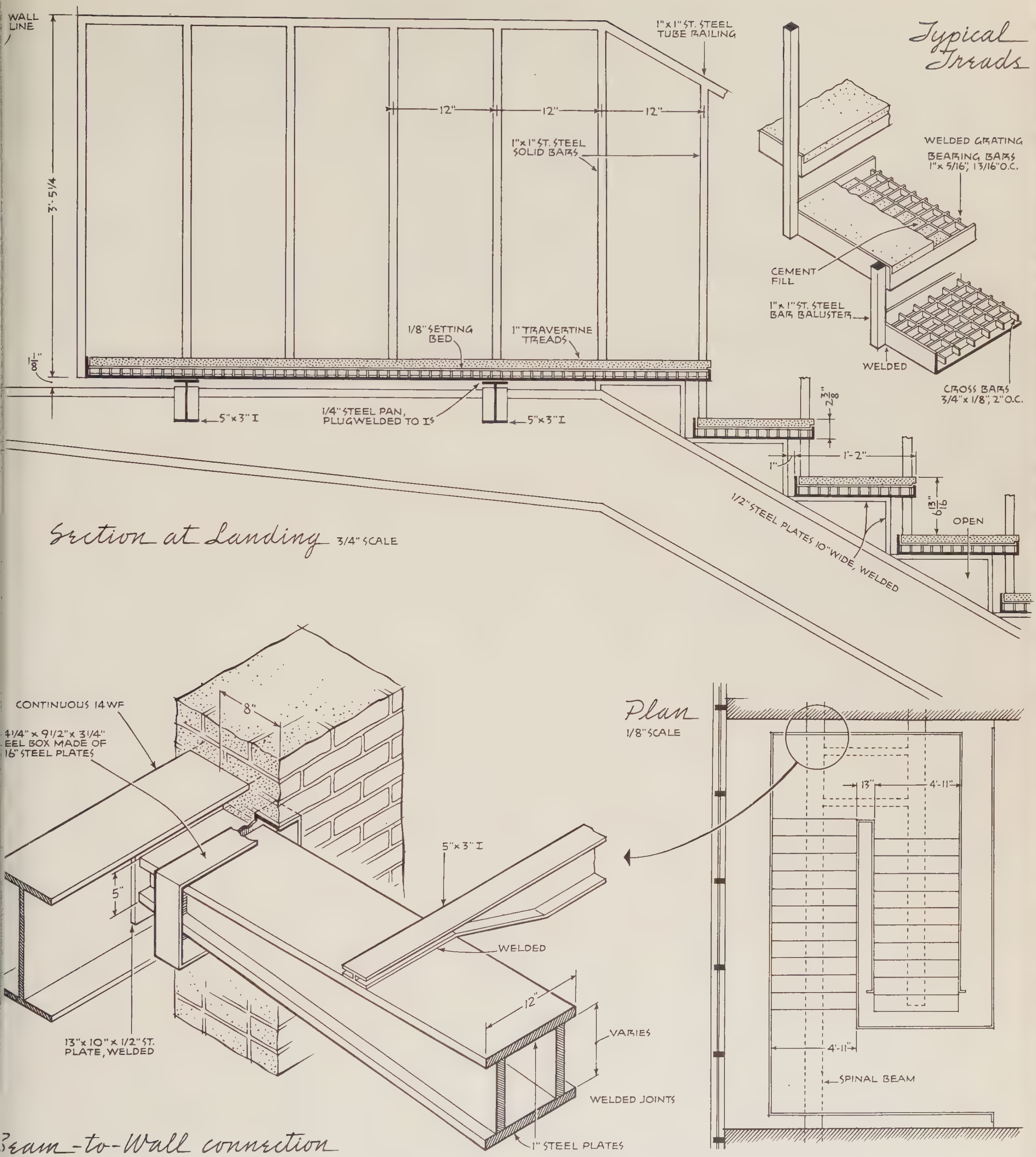


Fig. 9—Spinal-beam stair details are shown in this architectural drawing. For the beam-to-wall connection the flanged steel pan was sized to fit the brick coursing dimensions. Buried in the brick wall is a horizontal structural beam to receive this connection. The rectangular structural mullions in the exterior wall are on 5-ft centers. Since the entire structure is exposed, all welds are continuous and are carefully ground.

Fig. 10—A single-column support for the up-swept canopy of the Technical Center Service Section Administration Building presented some interesting engineering problems and afforded the architects an opportunity to introduce the curved shape of the column into the building details. The four small circles about the top of the column are recessed down-lights. The canopy soffit is cement plaster. The plaster is on the same plane as the bottom of the facia steel and is held one inch away from the steel to provide for condensation weepage and to prevent cracking due to steel movement.

participation. Each prospective group or tenant to be housed at the Technical Center designated an engineer to serve as a single representative for his activity. Each activity, of course, made extensive use of its respective Plant Engineering Department. The Styling Staff not only programmed its own requirements, but also accepted a major role as design consultant to the owner and to the architects concerning design features, color schemes, furniture and furnishings, and other components of interior decor.

Many technical problems arose concerning new building materials and their application. GM's direct contributions included (a) consultation on ceramics with AC Spark Plug Division concerning glazed bricks, and (b) consultation with Inland Manufacturing Division on the Neoprene glazing frame used for solving curtain-wall problems. Likewise, the Research Staff tested many of the new materials, and the Styling Staff designed the modular, luminous ceiling for its own buildings. Even some of GM's own plants made certain special items incorporated into the buildings.

This was the kind of a team GM thought necessary to create a fitting Technical Center representing management's vote of confidence in the engineering profession and its role in the development of the products of tomorrow

ACKNOWLEDGEMENTS

Drawings

Smith, Hinchman & Grylls, Inc.
Figs. 2, 3, 6, 11, 12, 13, 14

Progressive Architecture, E. A. Bennett
Figs. 7, 9

State Board Examination Problem

Michigan State Board of Registration for Architects, Engineers & Land Surveyors

Dr. Warren Yee, Smith, Hinchman & Grylls, Inc.

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Appendix

Structural Design of Canop[y] Technical Center Service S[ection] Administration Building

Problem

"A canopy 24 ft by 37 ft. The architectural design insists that it be supported by a single column, also that beams be limited to 18 in. maximum and 12 in. at edges. The column is considered hinged top and bottom. No hangers to the building are allowed. Sketch a system of framing to support the canopy. Actual beam sizes need not be detailed, but a brief description of the system is required."

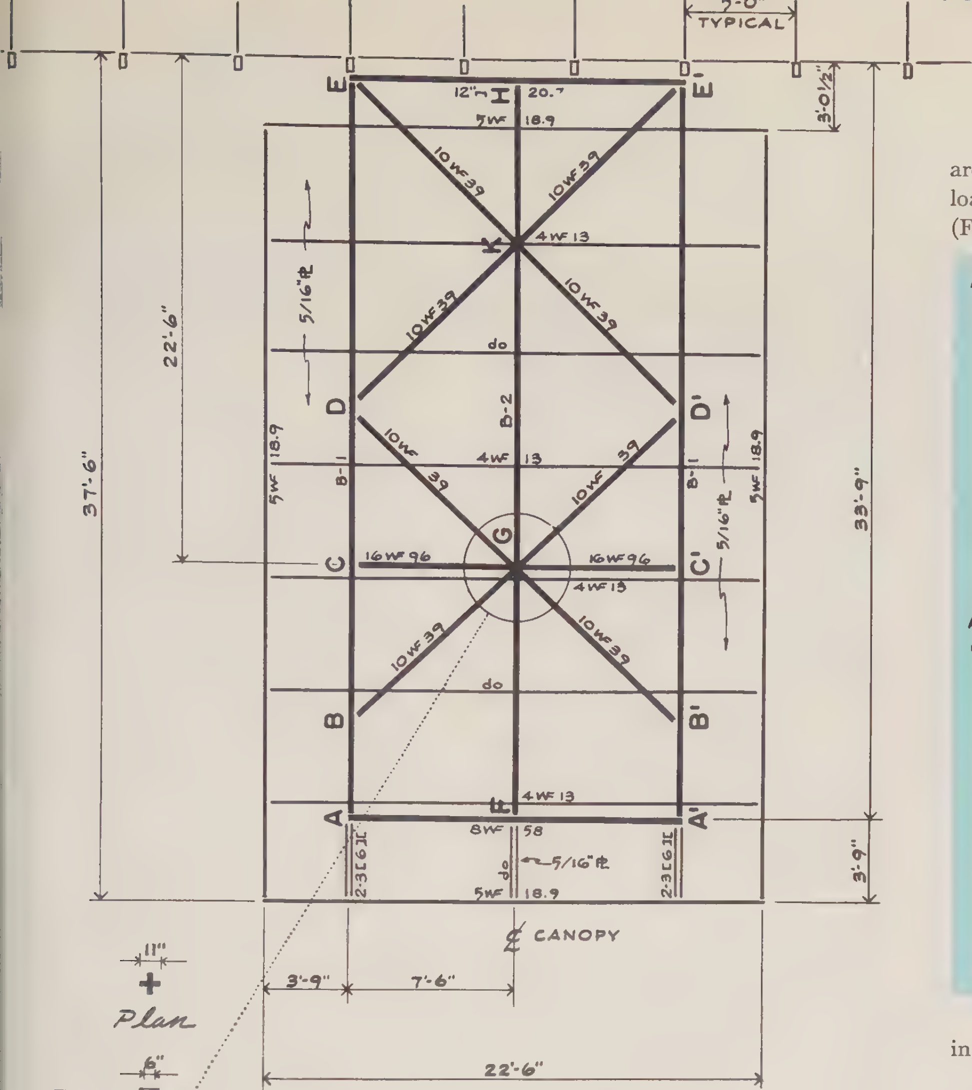
The test papers confirmed that there are several methods of framing which will satisfy the requirements. The actual solution for the Technical Center Service Section Administration Building is given below.

Solution

The canopy was designed for a live load of 30 lb per sq ft and a wind load of 30 lb per sq ft acting in any direction. The major members of the structural frame, *ABCDE*, *FGKH*, *A'B'C'D'E'*, *CGC'*, *BGD'*, *B'GD*, *DKE'*, *D'KE*, and *EHE'* were made continuous by welding (Fig. 11). Three loading conditions were assumed for the design:

(a) Upward or downward vertical loads acting on the entire canopy
(b) Upward or downward vertical loads acting on one-half of the canopy only
(c) Horizontal wind load.

For loading condition (a), assuming that vertical loads are applied symmetrically about the center-line of canopy, it is apparent that the structural frame formed by members *ABCDE, A'B'C'D'E'*, *CGC'*, *EHE* (Fig. 11) and the columns would be sufficient to carry these loads. Since the entire frame is in the form of a cantilevered horizontal truss, anchored to the building with its dead weight supported by columns, loading condition (b) can be taken care of easily. With a single column, hinged at top and bottom, as a support at approximately the center of the canopy, it is eccentric loading condition (c) that involves the primary design problems of stability and excessive deflection.



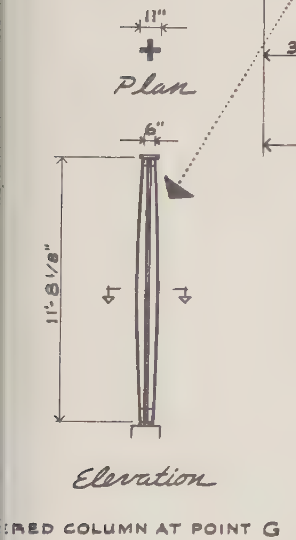


Fig. 11—This engineer's drawing illustrates the framing plan for the canopy of the Technical Center Service Section Administration Building. The capital letter designations refer to the engineering analysis of the examination problem illustrated further in Figs. 12 and 13. The dimensions indicate the size of the structural members used in the actual installation.

For condition (c) assume that loads are applied on line *ABCDE* only. These loads may be supported by members (Fig. 12).

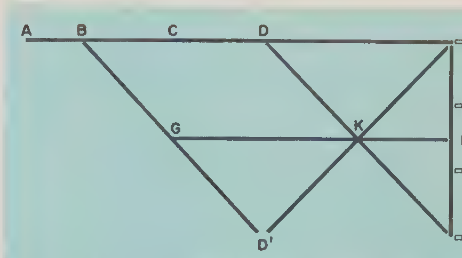


Fig. 12—This partial framing diagram refers to the examination problem analysis. The single-column support is located at point G.

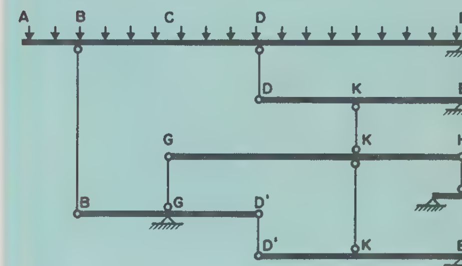
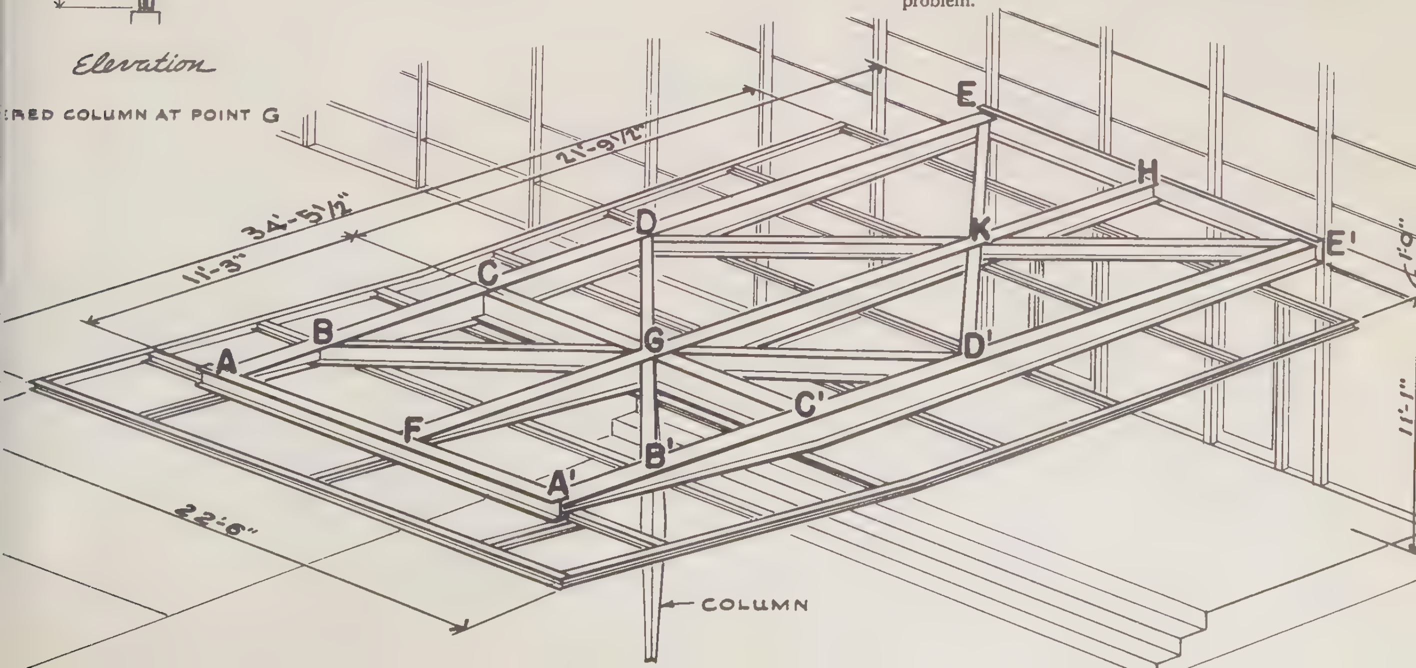


Fig. 13—The canopy loading diagram illustrates procedure of analysis in the examination proble[m]. Points *E*, *H*, and *E'* are located at the building exter[ior] wall.

The procedure of analysis is illustrated in Fig. 13.

To meet the architectural design requirement of slender-line edges, and still provide space for soffit and roof construction, a twin-level canopy was finally developed (Fig. 14).

Fig. 14—An isometric drawing illustrates the various horizontal levels of the framing members of the canopy. As in Figs. 11, 12, and 13, the dimensions and size of structural members are those of the actual canopy. The capital letters refer to the statement of the examination problem.



Styling in General Motors

Over a decade ago Alfred P. Sloan, Jr., chairman of the board of General Motors and architect of GM's unique decentralized organizational framework, envisioned a place having the atmosphere of a college or university campus where GM's Central Staff groups dealing with advanced creative thinking would be free to explore the future for new ideas and new concepts in automotive styling and engineering.

More recently Harlow H. Curtice, president of General Motors, described this continous search for new and better ways to accomplishment as "the attitude of the inquiring mind."

The inquiring minds of General Motors people are at work in many ways at the Technical Center. In this vast facility different groups bend their efforts in various directions—research, engineering, manufacturing development, and styling. But there is a singleness of purpose which binds all of these groups together—progress through technological accomplishment and continued General Motors leadership in providing more and better things for more people everywhere.

The stylist's role on the team of advanced creative thinkers at the Technical Center is significant, for it is his lot to arouse in that all-important person, the customer, a flair for fashion through skillful application of the elements of design—line, plane, form, and surface quality.

Stylists, like scientists and engineers, are a breed apart from most other groups. By the very nature of their profession they must be restless and dissatisfied with the look, the appearance, of things as they are. They must be dreamers, but practical ones. They must hold as unbreakable the rules of good taste.

In the design of commercial products stylists must always be aware that they have one boss above all others—the buying public. To turn a deaf ear to public desires can prove disastrous in the field of industrial design.

During the past 20 years General Motors has kept pace with public tastes in styling and engineering by building experimental or "dream" cars to test public reactions. Public reaction to these cars is carefully tabulated and the results heeded. Since being originated by General Motors nearly 20 years ago, the idea of building experimental cars has been used by manufacturers throughout the industry. It is an important part of General Motors industrial design program today and has been carried over into the fields of truck, Diesel locomotive, and household appliance design.

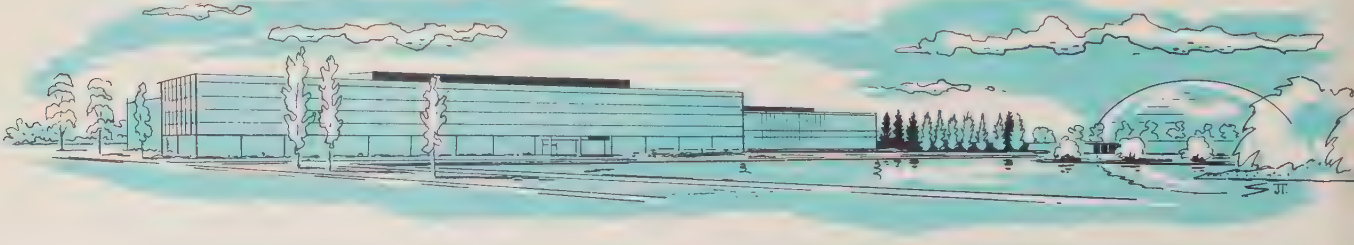
It is logical, then, that the Styling Staff should be located at the Technical Center, heart of General Motors research and experimental operations. There are, however, other important reasons for the Styling Staff's being a part of the Technical Center.

The purpose of the stylist's efforts is provided through research and engineering. Only after efficiency, durability, and quality have been engineered into a product can a stylist honestly set himself to the task of applying to the product beauty and grace of line.

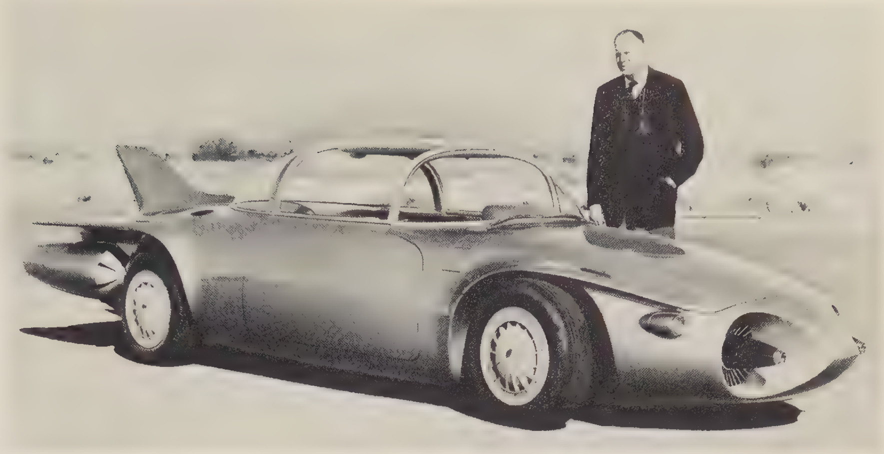
The most gracefully styled automobiles in the world would not sell year after year if it were not soundly engineered. On the other hand, a well-engineered automobile would have trouble on the competitive market if distastefully designed. The same is true for stoves, refrigerators, or Diesel locomotives, which points up in still another way the singleness of purpose of the groups occupying the Technical Center.

One of the most dramatic results of the partnership in progress that exists at the Technical Center is the Firebird II, General Motors new experimental gas turbine passenger car (Fig. 1). The revolutionary gas turbine engine of the Firebird II and other engineering features were developed by the Research Staff. The Engineering Staff developed the car's special transmission. Among the General Motors Divisions participating in the Firebird II program were Saginaw Steering Gear, Moraine Products, Delco Products, Delco-Remy, Diesel Equipment, Harrison Radiator, Hyatt Bearings, New Departure, and AC Spark Plug Divisions.

The Styling Staff assumed responsibility for the Firebird II body design and developmental program. In developing this design three important factors were taken into consideration:



By HARLEY J. EARL
Vice President
in charge of
Styling Staff



★ Fig. 1—The design and developmental program for the Firebird II experimental gas turbine passenger car was based on three factors: (a) to report to the public General Motors progress in the development of a new form of automotive power, (b) to serve as a laboratory on wheels for testing the many new automotive engineering concepts embodied in the design of the Firebird II, and (c) to give dramatic evidence of the advancements made in gas turbine development and other engineering concepts without creating the impression that these developments would appear on 1957 model cars.

(a) The Firebird II was to be, in effect, a report from General Motors to the nation on its progress in development of a new form of automotive power

(b) It was to be a laboratory on wheels for a number of new automotive engineering concepts being tried for the first time

(c) It was to dramatize the advancements which had been made in gas turbine development and other engineering concepts without creating the false impression on the part of the public that these new developments would appear on their 1957 cars.

To accomplish these aims the Firebird II was designed in spectacular aerodynamic fashion, continuing the design theme established two years earlier when the experimental Firebird I was introduced. To further emphasize the progress the car was to represent, it was designed for adaptability on a theoretical highway of tomorrow. The Firebird II was presented that way in the 1956 Motorama. A filmed version of how the car would operate on such a highway was dramatically presented in color in the Motorama.

To touch off the futuristically designed and engineered Firebird II, the stylists decided to fashion the body of titanium, the "wonder metal" which is abundant in the earth's surface but which presents serious problems so far as welding and plating are concerned. No such use ever had been made of titanium. A body of this metal would indeed complete the story of progress the car was to represent. It was accomplished.

The Firebird II is a product of the Technical Center. It represents as well as any other single thing the purposes of the Technical Center and is symbolic of the advanced thinking and planning that goes on there.

Since the various groups which operate within the Technical Center are so closely and vitally concerned with progress, they quite logically deal in another "product" which is vital to the automobile industry and our entire economy—obsolescence.

By creating new features and new products, it is the hope of General Motors each year to render obsolete those products which have come before. Research deals in long-range obsolescence. Engineering deals in a stepped-up, but still evolutionary, kind of obsolescence.

In styling, however, where noticeable change must come annually, it amounts to *dynamic obsolescence*—the creation of a desire on the part of millions of car buyers each year to trade in last year's car on a new one is highly important to the automobile industry. The annual model change is directly responsible for this yearly trade-in situation. Since the design of the automobile is the first thing the buyer sees, the stylist is more continuously involved in the annual change. The importance of engineering changes, however, cannot be over estimated, but by their very nature they cannot be changed annually as much as can the appearance of the car.

Thus, the design of the car can be a persuasive tool for inducing car buyers to get rid of the old and buy the new. In presenting new designs annually the stylist must depend to a large extent on the developments brought about through the research and engineering processes. In designing cars lower to make them more attractive, the stylist is often limited by engineering factors. However, as engineers develop methods of lowering the car, the stylist is allowed increasing latitude in his task of making it attractive.

Perhaps no other single factor has had such an effect upon our American standard of living as the annual model change. It has spread from the automobile field into other fields and still is finding increasing numbers of products as years go by.

Using the automobile as an example, consider the fact that for every year-old car that is traded in on a new model a like-new used car becomes available at used car prices. This allows persons who could not afford a new car to purchase much-needed transportation. As a car becomes two years old, it is priced still lower and is available to a person in another income bracket. Thus, through the used car market, which is a product of the annual model change, persons all along the economic scale can own automobiles they might otherwise be unable to afford.

The role played by the stylist in the entire industry and, in fact, the economy of the nation is one of significance. It is the stylist's nature to want to change things to make them more desirable and attractive to the customer.

All change in the design of industrial products must be toward the more functional, the more attractive, the more saleable product. Otherwise it is not change, but rather retrogression.

Progress is one of the products of change—one of the important products. At the Technical Center, where progress flourishes, General Motors Styling Staff will continue to improve its products.

Styling Staff Facilities

When the General Motors Styling Staff was formed 30 years ago, its personnel numbered less than a dozen people and all of its activities were housed in a single room. In the interval GM Styling Staff has grown into an organization of 1,100 men and women. In addition to the sketching and body drafting that engaged the original group, there are many other skills employed today. Modeling in clay, casting in plaster, and fabricating in glass fiber and metal are necessary to the design of future General Motors automobiles. The new facilities provided at the Technical Center are ideal for these creative activities.

If Leonardo da Vinci were alive today and pursuing his many artistic and scientific endeavors, he could find no better place to work than in the facilities of the GM Styling Staff as they now exist at the General Motors Technical Center. Here he would find ideal conditions for designing, painting, inventing, and advancing the sciences. Here he would find all of the technical skills so necessary to his inventive and resourceful mind: metal working shops, woodworking shops, sculpture studios, shops for fabricating glass fiber and plaster, and spacious design studios.

The same facilities and skills that would have such great appeal to da Vinci, if he were here to enjoy them, are greatly appreciated by the members of the Styling Staff, who are engaged in styling the products of the various General Motors Divisions. In addition to the many practical advantages to be found here, there is the appealing atmosphere of the university campus which is conducive to creative thinking.

One of the biggest advantages to the professional designer is the lighting condition that prevails throughout the studios and in the Auditorium. The brightness and evenness of light, the absence of shadows, and the spaciousness of the rooms permit better evaluation of proposed designs and contribute to improved appearance in future products.

A glance at the plan view of the Styling buildings reveals five separate areas (Fig. 1). On the north side, facing the lake, is the Administration Building which houses the main reception lobby (Fig. 2), offices, cafeterias, library, and product and exhibit design studios. Adjacent to the Administration Building lies the Interior and Color Studio which caps the ground floor garage.

Connected to the Interior and Color Studio to the south is the large Studio and Shop Building.

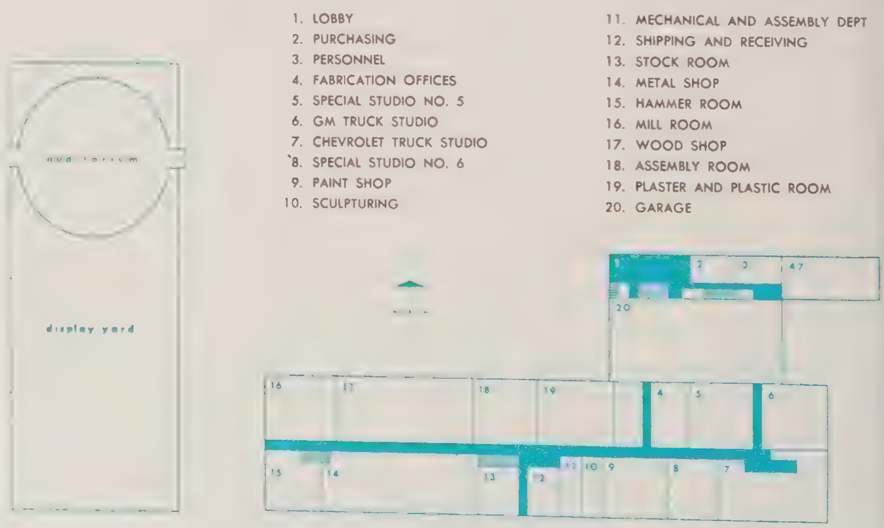
To the west of the Administration Building lie the huge, domed Auditorium and the wall-enclosed Display Yard.

The overall architectural approach shows complete understanding of, and sympathy with, the problems of a modern styling activity. Perhaps this is quite natural since the two activities—architectural design and industrial styling—are closely allied. This discussion will be confined to the facilities and tools which are closely connected to the daily activities of the GM Styling Staff rather than to the overall architectural scheme.

The Interior and Color Studio

Between the Administration Building and the Shop and Studio Building lies the Interior and Color Studio (Fig. 3). This Studio is a "faceted circle," having a 78-ft diameter outer glass wall and an inner glass wall 24 ft in diameter open to the sky. The purpose of the inner glass wall in the center of the room is to provide daylight viewing conditions throughout the entire area of the studio.

The dominant facility within the Interior and Color Studio is the free standing *color selector*, specially designed and built for GM Styling (Fig. 4). It holds 3,888 metal samples of colors and provides an absolute color scale by which



FIRST FLOOR

Fig. 1—The facilities of the GM Styling Staff buildings are divided into five separate areas—Administration, Product and Exhibit Design Studios, Interior and Color Studio, Design Studios and Shops, and the Auditorium and wall-enclosed Display Yard.

By WILLIAM L. MITCHELL
General Motors
Styling Staff

Stylists anticipate the future by combining creative thinking with engineering facts

all tints, shades, and chromatic colors can be identified and graded. Actually, there are six sections in this display, each of which is capable of rotation at the touch of a button. Within each section are eight vertical columns of samples which can be rotated by hand.

Anyone familiar with the phenomena of color knows that the light conditions are all important in viewing and comparing pigments. To eliminate difficulties of this nature an Interior Color Matching Studio has been provided within the Color Studio. A closed form 14 ft in diameter, this little room has an exterior wall of patterned aluminum and an interior wall surface of ribbed white plastic. Overhead there is a ring of blue-white light that approximates light conditions of a cloudy, bright day. To simulate sunlight or other light sources there are red and blue spots controlled by rheostats. By recording the light used on a certain occasion, it can be duplicated at any time later on.

The Design Studios

Imagine a room 80 ft by 55 ft with a ceiling that slopes gently upward to meet a room-wide window which reaches from floor to ceiling (Fig. 5). Picture a ceiling covered with soft, luminous squares of light, so effective that there is no glare or shadow in any part of the room and the light intensity is 95 foot candles at desk height. This lighting arrangement, developed by GM Styling Staff, is essentially a ceiling covered with large, specially molded, transluscent plastic pans. Behind these pans, at a distance which prevents any concentration of light, are located thousands of individual fluorescent tubes. The system has proved so effective that it has been used in other styling rooms and is being widely used in modern buildings now under construction.

Each of the Design Studios has four sets of vertical drawing boards along the side walls (Fig. 6). The outer boards in each set are movable in a vertical direction and are counter balanced by weights.

In addition to a drawing table, each designer and engineer has a portable table in which he keeps the sweeps and other tools of his profession.

There is sufficient room in each studio for as many as four full-size cars or clay mock-ups, still permitting the designers enough room to properly evaluate their designs.

The Shops

The fabricating shops are worthy of special mention. In the metal, wood, plaster and plastic, paint, and trim shops work some of the finest craftsmen in the

Fig. 2—In the main reception lobby the hanging staircase, extending from the first to the second floor, is supported by stainless steel rods. Located on the first-floor level beneath the staircase is a pool. Adjacent to the reception lobby is a display area where GM production model and experimental "dream cars" are placed.

21. EXECUTIVE OFFICES
22. SECOND FLOOR LOBBY
23. PRODUCT AND EXHIBIT OFFICES AND STUDIOS
24. INTERIOR AND COLOR STUDIO
25. OFFICES
26. LIBRARY AND CONFERENCE ROOM
27. INTERIOR DESIGN STUDIOS
28. CUTTING AND SEWING
29. TRIM STOCK
30. TRIM ASSEMBLY
31. SPECIAL STUDIO NO. 4
32. INTERIOR ENGINEERING
33. DRAFTING AND ENGINEERING
34. SPECIAL STUDIO NO. 2
35. SPECIAL STUDIO NO. 1
36. CADILLAC CAR STUDIO
37. BUICK CAR STUDIO
38. OLDSMOBILE CAR STUDIO
39. PONTIAC CAR STUDIO
40. CHEVROLET CAR STUDIO
41. ACCOUNTING DEPT.
42. PRIVATE DINING ROOMS
43. KITCHEN
44. CAFETERIA
45. EMPLOYES' LOUNGE
46. FRIGIDAIRE STUDIO
47. EXHIBIT STUDIO

SECOND FLOOR

THIRD FLOOR

Fig. 3—The 78-ft diameter glass walled Interior and Color Studio, where fabrics and colors are displayed and selected, has a 24-ft diameter inner glass wall (partially shown at the right) which is open to the sky. This inner glass enclosure provides daylight viewing throughout the entire area of the studio. Shown in the foreground are display tables. At the left is a passenger car seat used for fabric selection purposes, and to the right, next to the inner glass wall, is an instrument panel mock-up. In the center background is the free-standing color selector which holds metal samples of colors.

country. They deserve the best in tools and facilities because these are the men who hand-build the General Motors "dream," experimental, and prototype cars. Their work involves the shaping, fabricating, fitting, and assembling of all of the thousands of carefully designed parts that go into these automobiles. It is careful, exacting work and requires the best of working conditions.

There are several advantages common to all the shop areas. All are spacious, being located under a span of 80 ft. All are air conditioned, and all have polished, edge-grain maple floors. Each shop is equipped with individual work benches and built-in tool boxes (Fig. 7). The

Fig. 4—The free-standing color selector located in the Interior and Color Studio holds 3,888 metal samples of colors. The selector provides an absolute color scale by which all tints, shades, and chromatic colors can be identified and graded. Located below the counter are file drawers containing duplicate chips of all the colors displayed.

Fig. 5—This picture of one of the Styling Staff's 80-ft by 55-ft Design Studios, taken through the clear glass wall of a chief designer's office, shows a portion of the unique ceiling lighting arrangement which prevents glare or shadow in any part of the Studio and provides a light intensity of 95 foot candles at desk height. Shown along the side wall are vertical drawing boards which allow full-size design sketches and drawings to be made. The designers' desks (background) are located along the floor-to-ceiling windows.

wood shop and plaster and plastic shop have underfloor ducts for the removal of dust, wood sawdust and chips, and glass fiber dust. All debris is directed to collectors in the basement.

In the metal shop are complete facilities for shaping, forming, and finishing metal, as well as for welding and brazing.

In the wood shop, where the precision mahogany patterns are made, many woodworking machines are located. Here too, forms are made for hammer-forming sheet metal automobile components and for making glass fiber sections.

In the plaster and plastic shop, crews of skilled men assemble and surface finish the plaster molds taken from full-size clay mock-ups of automobile hoods, doors, and fenders (Fig. 8). Overhead cranes facilitate handling the heavy plaster sections, some of which weigh as much as 3,000 lb.

The Auditorium

Members of the Styling Staff spend a great deal of time looking at automobiles. They look at clay models, glass fiber prototypes, sheet metal versions, production models, and component parts. Under what conditions should these cars be viewed so that their merits can best be judged? When the architect, Eero Saarinen, posed this question to the Styling Staff several years ago, it was determined that a bright, overcast sky, such as found outdoors on early spring days, would be the best condition for critical viewing.

In the new Styling Auditorium dome is the closest thing to this condition that artificial lighting is capable of producing. The dome is 65 ft high and covers a span of 186 ft. The inner dome is made of perforated steel, painted white. The effect is one of great depth.

The extraordinary lighting system is so flexible that the lighting level throughout the Auditorium can be varied from complete darkness to a daylight level of 140 foot candles. The lighting is indirect and is powered by 140 1,000-watt incandescent lamps and 140 500-watt mercury vapor lamps, all of which work on dimmers. Near the center of the dome are four openings for concentrated spots of light each having 3,000 watts and duplicating the direct rays of the sun.

The Auditorium floor is of medium grey vinyl. The walls are covered with aluminum mesh relieved by vertical aluminum slats.

Fig. 6—Each Design Studio has four sets of vertical drawing boards. The outer boards move in a vertical direction and are counterbalanced by weights. Located between each set of boards is a storage cabinet. Shown here is a designer in the process of making a full-size sketch on one of the outer boards. Shown on the bottom board at the right is a partial view of another full-size rendering of a GM Motorama show car. The bottom board at the left holds various imaginative design sketches. ★

Fig. 7—Typical of the facilities in the various fabricating shops of the Styling Staff are the individual work benches and custom built-in tool boxes. Shown here is a portion of the metal shop which shapes, forms, and finishes metal, in addition to doing welding and brazing work. ★

In addition to the central area where dozens of cars can be viewed, there is an elevated stage which holds three turntables. These are ideal for displaying new experimental models, permitting a quick survey from every possible angle.

Because the advance styling of automobiles must be kept secret due to the competitive nature of the field, there is a connecting underground passage which leads to the Shop and Studio Building, through which the cars of tomorrow pass freely under their cloth drapes. This has proved to be a very convenient arrangement.

The Outdoor Display Yard

To the south of the Auditorium and visible through its stage window-wall, lies the outdoor Display Yard, a sort of twentieth century cloister surrounded by trees and foliage.

Fig. 8—In the plaster and plastic shop assembly and surface finishing work is carried out on plaster molds taken from the full-size clay mock-ups of automobile hoods, doors, and fenders. All of the various fabricating shops are air conditioned. In addition, the plaster and plastic shop and the wood shop have a special underfloor duct system for the removal of all dust and chips.

Fig. 9—The drafting room of the Styling Staff's Engineering Department has the same unique ceiling lighting system as found in the various design studios. This lighting system prevents glare or shadows and provides equal light intensity in all areas of the room.

Here summer showings of proposed designs will be conducted. The surface of the Yard is paved with a specially developed brownish-red, hexagonal brick. In the south end of this area are located three mechanical turntables.

A coaxial cable runs underground from the Auditorium to the Yard so that a television truck can plug in at this end of the cable while cameras televise in the Auditorium interior.

Engineering

Few people realize that engineering is a highly important function in the activities of the GM Styling Staff. There are as many people engaged in engineering activities as in appearance design.

Included under the heading of engineering in the GM Styling Staff are departments for drafting, engineering, and shop technology; a fabricating shop; and supervision. Found among these groups are experts in convertible top mechanisms, roof panels, memory door-locking devices, special seat mechanisms, and body structures.

It is quite natural, therefore, that the engineering facilities match those of the Design Studios. Here, too, are found the typical full-size horizontal drawing boards and the aluminum sweeps so necessary to automotive body drafting (Fig. 9).

Summary

GM Styling Staff facilities are provided for the various processes of design and drafting, fabrication, and exhibition of automotive vehicles. The Interior and Color Studio is well equipped for the selection and evaluation of a complete range of tones and tints. From the drawing boards of the men in the Design Studios come the "dream cars" of tomorrow; in the fabricating shops these sketches are worked into prototype realities. The domed Auditorium and outdoor Display Yard provide space for the exhibition of the latest style automobiles and prototypes of the future under controlled lighting conditions indoors and direct sunlight outside in the summer.

The prototypes of the production cars of the next few years and the imaginative designs of what may well be the conveyances of the next few decades are on the drawing boards and in the fabricating shops of the Styling Staff today as design stylists and automotive engineers combine their efforts to make today's dream become tomorrow's reality.

Development of a New Concept in Panel Delivery Truck Design

By HARLEY J. EARL,
CHARLES M. JORDAN,
and WILLIAM F. LANGE
General Motors
Styling Staff

n designing an automotive vehicle for mass production it is advantageous to make hanges of an evolutionary rather than a revolutionary nature. Therefore, the oppor-unity to develop a radically new concept does not occur too often. Just such an oppor-unity, however, did occur in 1954 when the General Motors Styling Staff conceived he idea of a new front-wheel drive panel delivery truck. In cooperation with the General Motors Engineering Staff and GMC Truck and Coach Division, GM Styling actually onstructed a prototype model which had such great appeal when shown to 1955 GM Motorama audiences that it is now being considered for production. The process lescribed here—that of designing, engineering, and fabricating a "dream truck"— arallels that of the custom body shops of years gone by.

Creative engineering in the styling of automotive vehicles

IN THE Spring of 1954 executives and designers of the General Motors Styling Staff met to discuss plans for the next GM Motorama, scheduled to open in anuary 1955. Within the intervening en months a new and different group of xperimental "dream cars" were to be lesigned and built.

In addition to the usual assignments to e discussed there was a challenging new dea on the program. With all the atten-ion in past years going to automobiles or Motorama display, why not develop "dream truck?" Such a truck should ot only be new and good looking but ntirely different from conventional rucks. The group decided that it was to e a panel delivery truck. That, briefly, s how GM Styling inaugurated the 'dream truck" developmental program —first designated as experimental Ve-icle XP-39 and now known as L'Uni-erselle all-purpose vehicle.

Several Styling designers made pre-iminary sketches of conventional panel lelivery trucks in an attempt to analyze he basic problem and to define the bjectives of the program. The specific oals established for the "dream truck" vere: (a) maximum load volume in a ninimum package size, (b) greater acces-ibility to the load, and (c) passenger car omfort, including visibility.

In the opinions of the Styling designers he floor of the conventional panel truck vas much too high, a fact which made npossible the efficient use of potential olume within the body and which put he overall height at an undesirable level rom an appearance standpoint.

The Styling designers reasoned further that with the engine in front, the frame height is fixed at its present level by the conventional drive shaft and rear axle. Nothing much could be done to alter the appearance of panel delivery trucks as long as this basic limitation existed. Why not change this relationship? Why not eliminate the drive shaft, relocate the engine, and drop the load floor as close to the ground as possible?

Here was a project with appeal and challenge for Styling designers. It was a design problem free of the many restrictions typical of designing for a mass product.

The Place of Styling in the Manufacturing Process

One purpose of this paper, in addition to telling the story of the design and fabrication of a successful GM Motorama Show Car, is to help clarify the complicated relationship between the GM Styling Staff, the Central Office Engineering Staffs and Divisional manufacturing groups.

In a vehicle intended for actual production the GM Styling Staff has two major responsibilities: (a) to develop exterior body surfaces, and (b) to design the interior compartment, which includes the appearance factor and all dimensional relationships. The end product of GM's Styling Staff is a set of full-scale surface drawings plus a detailed layout of the interior, all of which have been approved by Central Office and Divisional executives. GM Styling Staff, of course, also designs such details as bumpers, grilles, exterior and interior trim, and instrument panels.

In a proposed production vehicle the chassis design is a relatively inflexible factor and one to which the stylist must adhere, although in the past many gradual changes have been advocated.

After the prototype design has been approved, design for production begins. This is a highly complex process that retraces all the ground covered by Styling. Every line, surface, and component must be adapted to production methods, analyzed for cost and feasibility, and calculated for safety and strength. Naturally, there is a good deal of give and take in the process. Some proposals may be altered for cost reasons. But if the aesthetic appeal is sufficient, the production engineer may be inclined to find a way of reproducing the section, or surface, or molding as is.

The combined abilities of the stylists and the engineers have an important bearing upon the success of the modern automotive concern. What good is a beautiful experimental car with a high performance engine if production and manufacturing engineers cannot reproduce them in quantities and of a quality that will sell? On the other hand, the best production teams cannot market a product that lacks aesthetic, and hence, sales appeal.

In the case of L'Universelle truck no plans for production were in the offing in April 1954. The immediate objective was to design and fabricate a show truck for use in the 1955 General Motors Motorama. Primarily, it was a styling experiment in a new concept of design. However, it also had to be practical and feasible enough to suit the most critical observer.

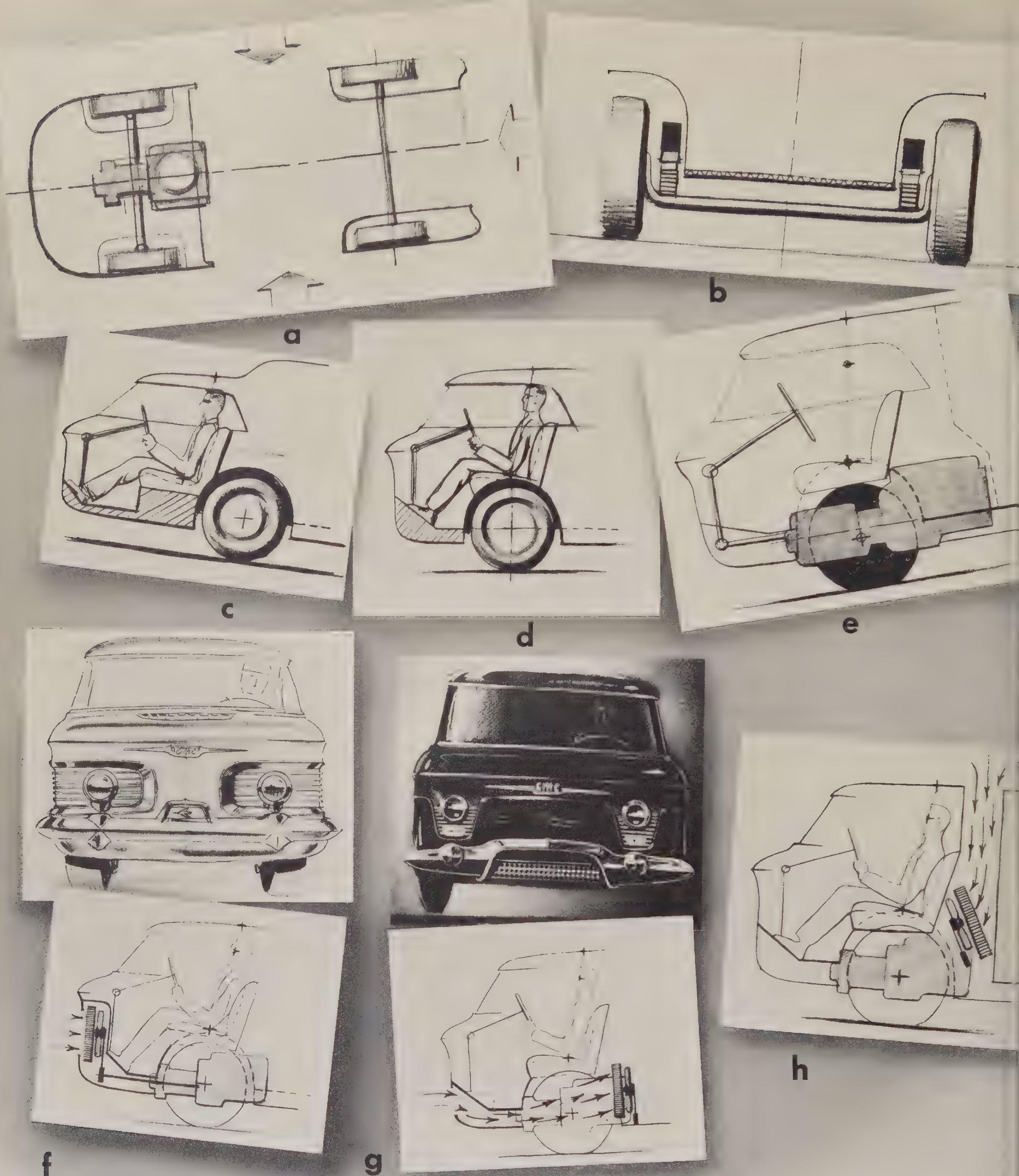


Fig. 1—Free-hand sketches by Styling Staff designers during the developmental stages of L'Universelle panel delivery truck aided in finalizing the basic design. Greater accessibility to load was obtained by providing a wide door opening on each side of the truck and a larger opening at the rear, in addition to locating the engine behind the front axle (a). The adoption of a drop-center rear axle considerably lowered the load-floor height from the ground level and increased maximum pay-load volume (b). The original idea of locating the driver's seat ahead of the front axle (c) was changed to a location over the front axle (d) so that minimum overall length would be maintained. Locating the driver's seat over the front axle provided space beneath the seat for locating the transmission with the engine, in turn, behind the front axle (e). Three ideas developed for cooling system location called for the radiator core and fan to be located immediately in front of the truck (f) in a split-core arrangement and also for the radiator core and fan to be placed behind the front axle with the air stream being directed from the front of the truck and under the driver compartment to the radiator core (g). The third idea, and the one used for the 1955 GM Motorama presentation, had the radiator core and fan located behind the front axle and at an angle to the engine (h).

The ability to develop this kind of vehicle required the efforts of two skills from the very beginning: styling designer and creative engineer. This assignment was far more than an appearance problem and demonstrates why the Styling Staff includes engineering talent.

Many of the designers on the Styling Staff have engineering educations and backgrounds. Within each studio design group are a number of automotive engineers. These men are just as interested in the mechanics of automobiles as in their appearance. In addition, there is a large Engineering Department. So, in the case of L'Universelle truck the beliefs and guesses and recommendations of Styling had a basis in practicability.

Although the GM Styling Staff does not attempt to design a chassis or adapt a transmission, it is aware, nevertheless, of the potentialities of various chassis arrangements. These men, in a very substantial way, are creative engineers. They conceive or lay out vehicles to which the skilled chassis engineer can adapt a frame, transmission, and a suspension system that are both workable and practical.

Developmental Engineering of L'Universelle Truck

During the early developmental stages of L'Universelle, many factors such as overall height, engine location, and driver's seat position were considered. In many instances sketches were made by Styling designers as a visual aid in arriving at a successful solution to the problems raised by all factors under consideration (Fig. 1).

One of the first considerations in the design of L'Universelle was to determine what minimum floor height would be possible if there were no drive shaft with which to contend. Because a floor laid over the conventional straight rear axle would be too high, it was proposed to design a drop-center rear axle. Why not arbitrarily locate this axle at what would be considered the minimum allowable ground clearance (about eight inches) for a vehicle of this type? This question was followed by some simple arithmetic —ground clearance plus diameter of the axle, plus allowance for jounce (vertical movement of the wheel within its housing), plus floor thickness. These dimensions totaled approximately 15 in. That is the height from the ground of L'Universelle truck's load floor.

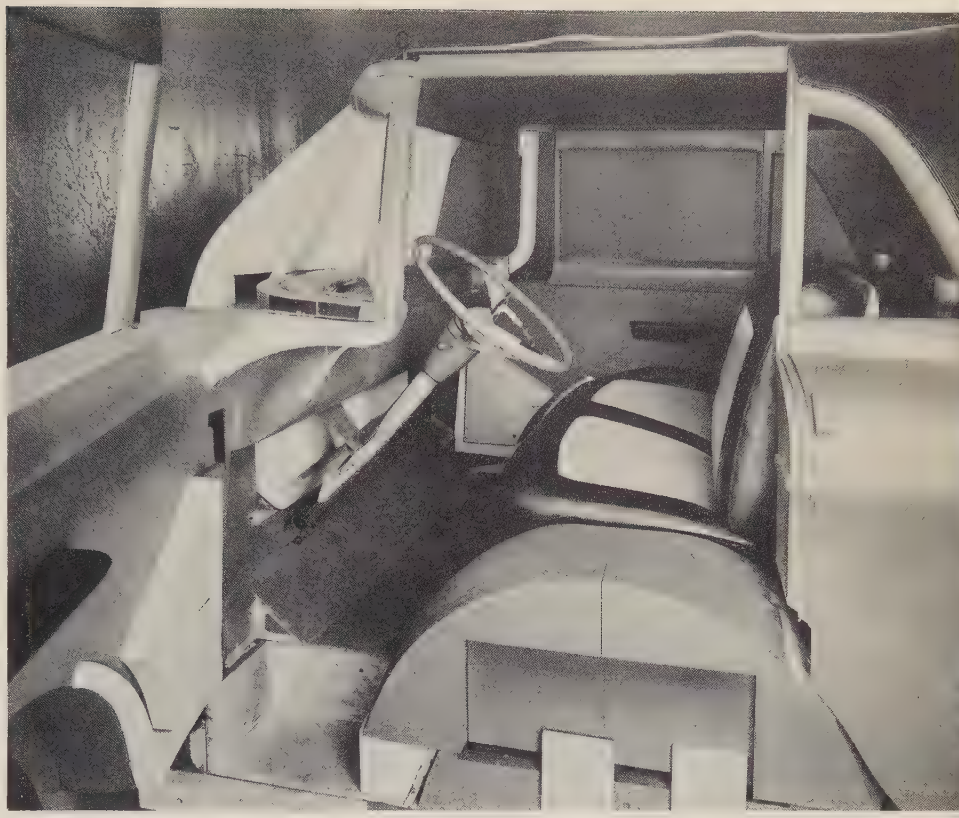


Fig. 2—A "seating buck," built to test L'Universelle's driver compartment entrance and comfort conditions, also served to establish the overall height of the vehicle. The 71-in. overall height was based on considerations given to tire size, wheel clearance space which located the wheel housings, depth of seat fitted between the wheel housings, head room as measured from the point of greatest weight concentration on the seat, and the thickness plus the crown of the roof panel.

Next under consideration was the relationship between engine and driver compartments. This had remained the same in automotive design for many years, although there are now and always have been advocates of rear-engine design. In American production automobiles high performance and comfort requirements make the location of the heavy engine behind the rear axle impractical from a weight distribution standpoint. For L'Universelle it was not proposed to move the engine to the rear of the vehicle but only behind the front axle where its location, weight distribution-wise, would be acceptable.

One of the initial aims was to provide passenger car comfort for the driver. This meant, among other things, comfortable seats, ample interior room, and bus-driver visibility. At first it was thought to put the driver's seat well ahead of the front axle, a move which would enable the designers to lower the silhouette of the front of the vehicle. But this had several disadvantages. The front over-hang of the truck (distance from front axle to tip of bumper) would then be excessive and the increase in overall length would be a retreat from the aim of maintaining a minimum package size. Also, it is known that, when in a position ahead of the axle, the driver is exposed to sidesway when making turns. Therefore, it was decided to locate the driver's seat over the front axle and to place it as low as possible for easy entrance and exit.

This arrangement seemed to offer the best solution to the problem. It allowed the driver to sit in a more vertical position. It reduced the amount of overhang in the front and provided a space beneath the seat which seemed ideal for locating the transmission with the engine immediately to the rear. After the layout was developed on paper, a "seating buck" (Fig. 2) was built to test the practicality of the comfort and entrance conditions.

It was this arrangement that established the overall height of the proposed vehicle. First came the diameter of the wheel (8.40 in. by 15.0 in. tire size); next the allowance for wheel clearance which located the wheel housing; then the depth of the seat which was fitted between the

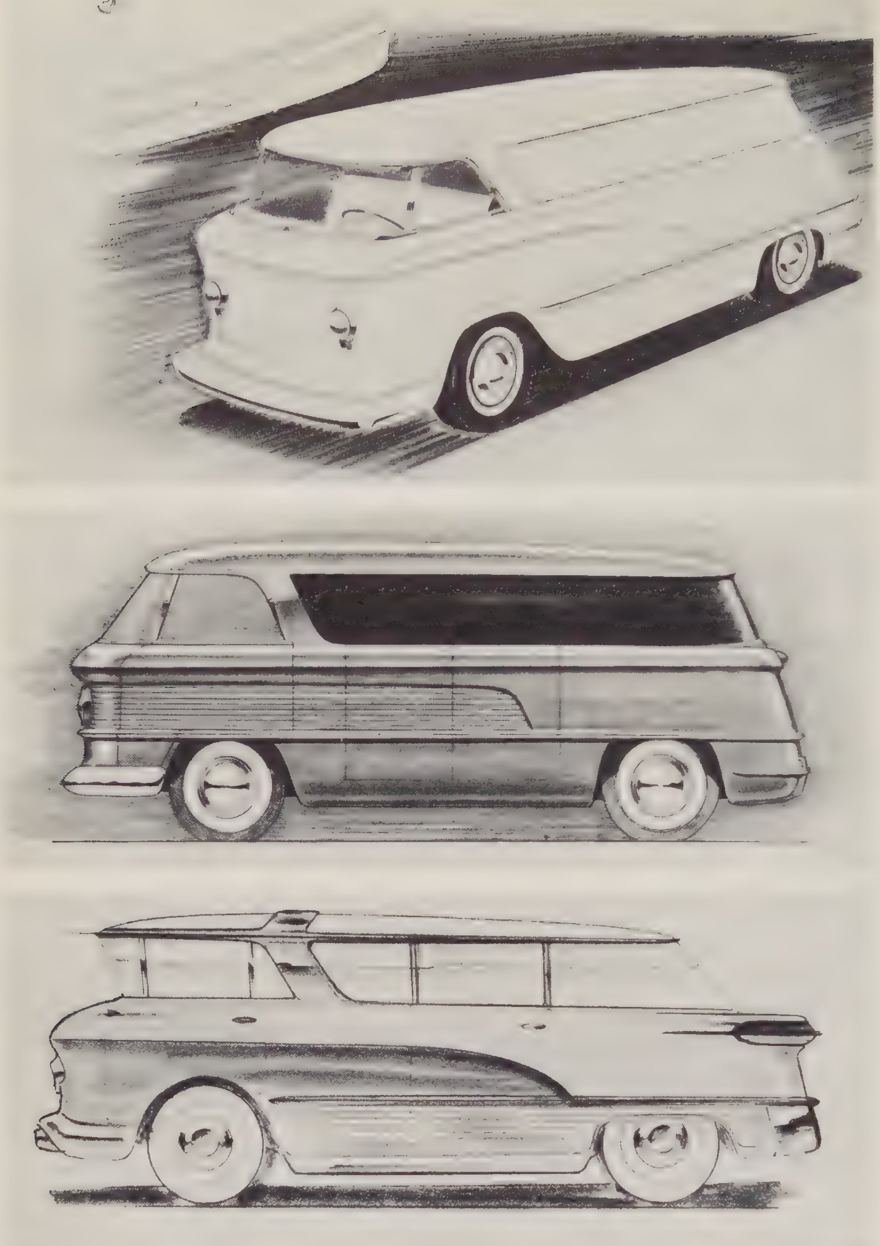


Fig. 3—Various design sketches, such as these by Styling Staff designers, were made to develop an exterior surface of L'Universelle "dream truck" which would express the new engineering concept. One of the first proposals (top) established the basic design idea which was eventually carried over into the final design. The center and bottom sketches represent additional thinking by the stylists as they sought to obtain just the right proportions in all of the various elements and the right character in all of the lines.

wheel housings; subsequently allowance for head room as measured from the "*A*" *point* of the seat (point of human weight concentration on the seat); and finally the thickness plus crown of the roof panel. These dimensions added up to 71 in. as compared to the 81 in. overall height of a conventional panel truck.

Along with the goal of providing maximum pay-load volume was the related objective of improved access to the load. This was to be obtained by adding a wide door on each side of the vehicle and providing a larger opening at the rear of the truck. These access openings, when combined with a low floor height, would make loading and unloading a comparatively simple procedure.

To reduce the size of the wheel housing within the load compartment the leaf spring was located immediately under the frame. This resulted in providing a width of 48½ in. between the wheel housings.

Up to this point all attention had been centered on localized problems: load floor location, overall height, and relationship between driver compartment and engine. In the next step, design sketches were made of a complete truck in which all of these proposed ideas were combined. In doing so one of the first considerations was to establish the wheel base and overall length. The front overhang had been established by driver compartment requirements. The rear overhang was fixed at the minimum so as to realize the maximum unobstructed load space between front and rear wheels plus a wide access opening at the side. As it turned out, the space available for the load compartment was large enough to permit a reduced wheelbase.

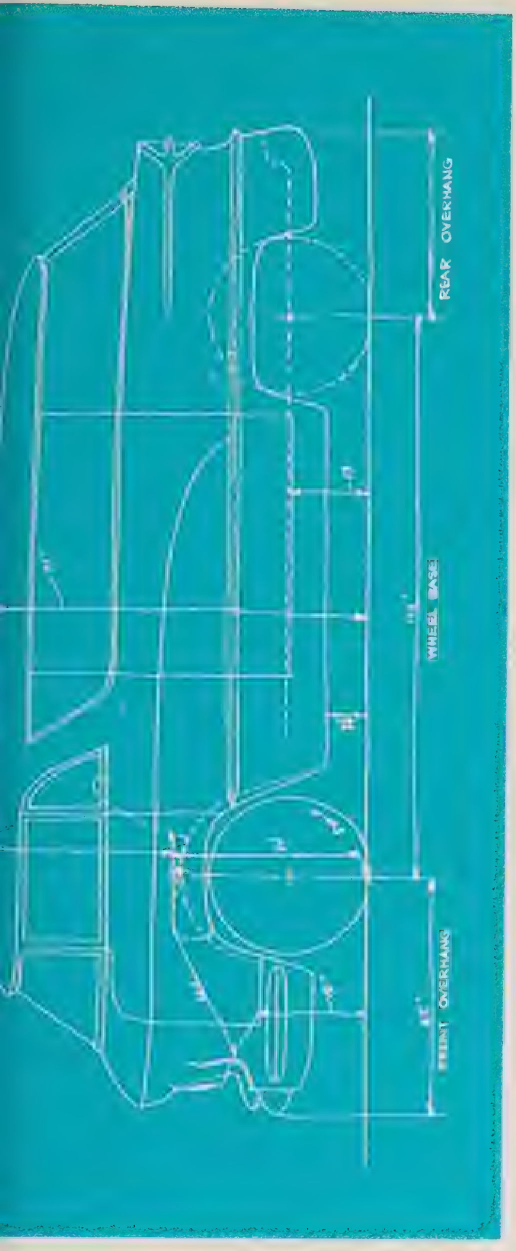
A 107-in. wheel base and later a 110-in. wheel base was specified instead of the conventional 115-in. wheel base. Now the basic dimensions of the proposed vehicle were fixed: 110-in. wheel base, 71-in. overall height, 188-in. overall length, 15-in. load-floor height, 16-in. cab-floor height, 46-in. front overhang, 9-in. road clearance, 36-in. rear overhang, 78-in. overall width, and a tire size of 8.40 in. by 15.0 in.

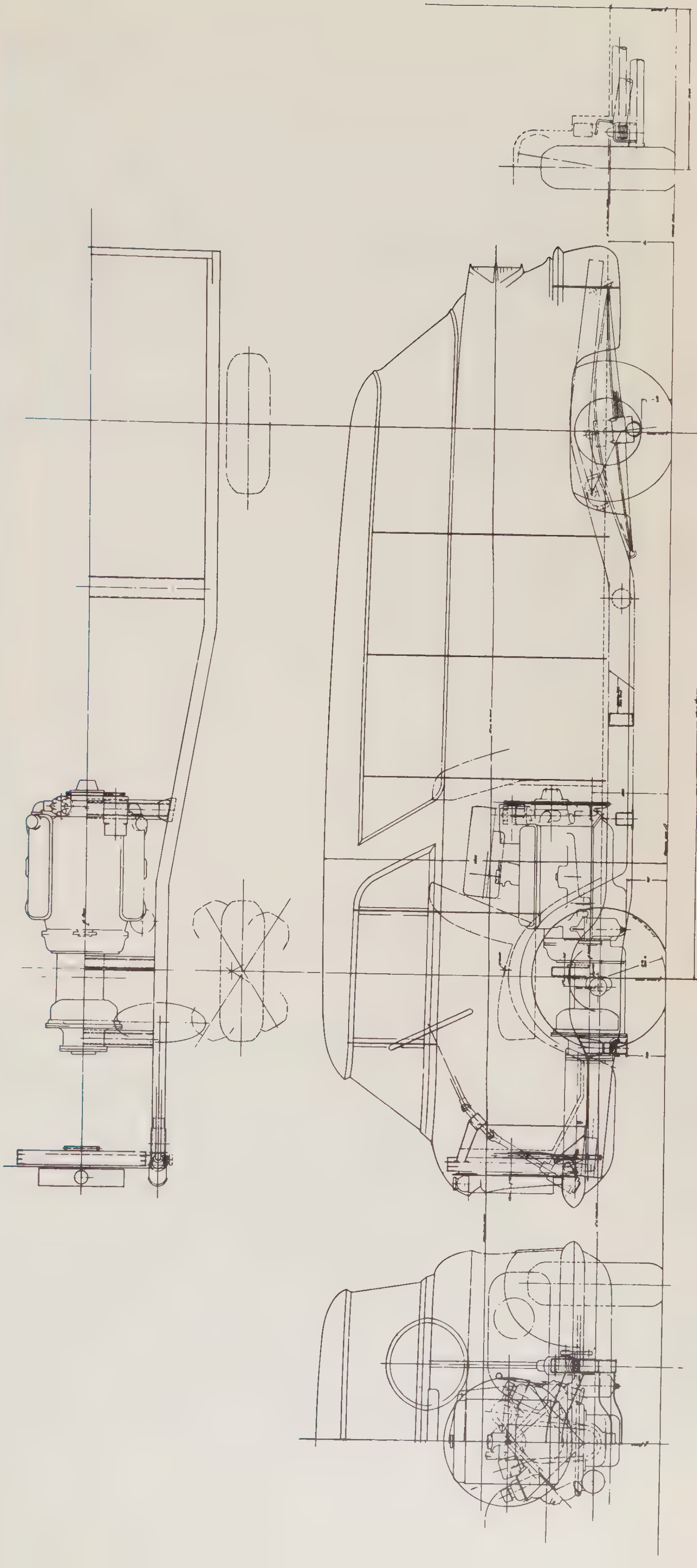
These dimensions were the basis for a three-month period of intensive design during which Styling Staff designers attempted to develop an exterior appearance which would express the new engineering concept (Fig. 3).

The absence of a hood, deck, or fenders accented the need for a new concept of appearance. Essentially, the truck was a rectilinear box. Now the problem was to give the box "shape"—to develop a form functional and pleasing to fit this new design concept.

Several design devices were employed. One was the use of full curved glass around the front and sides of the driver compartment, interrupted only by narrow door pillars. Another design device was the adoption of a horizontal edge or "blade" shape across the front of the truck just below the windshield. This shape was formed by the intersection of two curved surfaces. A continuation of the blade thus formed was extended around both sides. It gave a sculptured look and sloped downward in a way that visually helped "keep the rear end on the ground."

Since the possibility of converting this panel truck to a station wagon was considered, the panel which enclosed the load compartment was designed in sheet





;. 4—The Styling Staff requested the assistance the GM Engineering Staff to make engineering posals for L'Universelle "dream truck's" ssis, engine, and transmission components. A tch (inset) showing the proposed design was mitted to the Engineering Staff. After inten- e study of the problem, GM Engineering Staff lined specific recommendations for the various nponents and submitted both assembly and ail drawings of each component. Shown here is assembly drawing of L'Universelle "dream ck" submitted by the Engineering Staff which cified actual space requirements and general gn of each component.

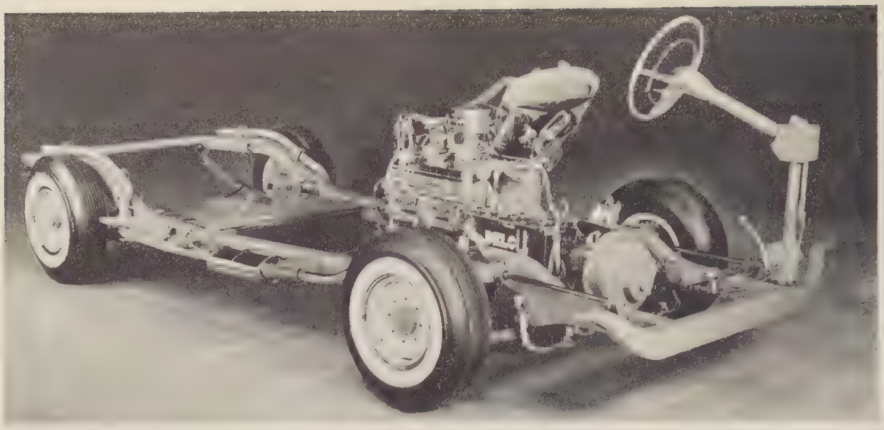


Fig. 5—An experimental chassis for L'Universelle "dream truck" was designed and constructed by the GMC Truck and Coach Division. This chassis embodied the principles conceived by the Styling Staff and developed by the Engineering Staff.

metal so that it could be easily replaced by glass. The designers were seeking a completely new look, a look which was to be exciting and pleasing. Many full-size drawings were made as the process of developing the design concept continued. What the stylists sought were just the right proportions in all of the various elements and the right character in all the lines.

In the early stages of L'Universelle development GM Styling Staff requested the assistance of the chassis engineers of the GM Engineering Staff to make a "guided-guess" proposal for chassis, engine, and suspension. To these men, experienced in developing mechanical components for advanced and experimental vehicles, the stylists presented sketches showing their proposed design.

What the Styling Staff requested were engineering proposals that would specify components to make L'Universelle a highly maneuverable and comfortable vehicle.

Thus began the developmental work on the chassis, power train, and suspension components. There were many engineering problems to be resolved. Some of the recommendations made by the Engineering Staff are as follows:

- *Frame*—Box section, double-kickup drop with arched cross member at transmission and removable strut between lower swing arm brackets
- *Suspension*—Rear: long-leaf springs and cast iron shock absorbers; front: torsion bar arranged to facilitate engine removal and a suspension linkage to provide convenient pivot points, low-roll center, and sufficient ball clearance at wheel
- *Power Train*—Modified 287 cu in. V-8 engine mounted behind the front axle; special three-speed transmission; front wheel drive through constant speed universal joints; front wheel brakes to be mounted on the outboard sides of transmission; radiator core and fan to be located forward of the cab in the nose
- *Steering Linkage*—Special linkage to allow required steering wheel position (horizontal position not allowable).

The recommendations of the GM Engineering Staff were based on a 1,000-lb payload and two possible types of bodies: (a) a panel delivery truck, and (b) a station wagon. Total curb load was figured at 3,261 lb with 60 per cent of this weight on the front wheels and 40 per cent on the rear wheels. Full load figures were 4,561 lb with 54 per cent of this weight on the front wheels and 46 per cent on the rear wheels.

Within a short time the necessary developmental work had been performed, and Engineering Staff provided Styling Staff with drawings (Fig. 4) which permitted a go-ahead on body and chassis construction.

By August 1954 Styling had begun the development of a full-size clay model to develop and refine the theme. The clay model is the proving ground of the design ideas as first developed in sketches and full-size drawings. When the clay model is completed, it is the basis for building a glass fiber prototype. Now was the time to proceed with actual design of the chassis. Although the exact future of the vehicle had not been determined at this time, it was at least partially a truck and as such needed the know-how of an experienced truck manufacturer to build

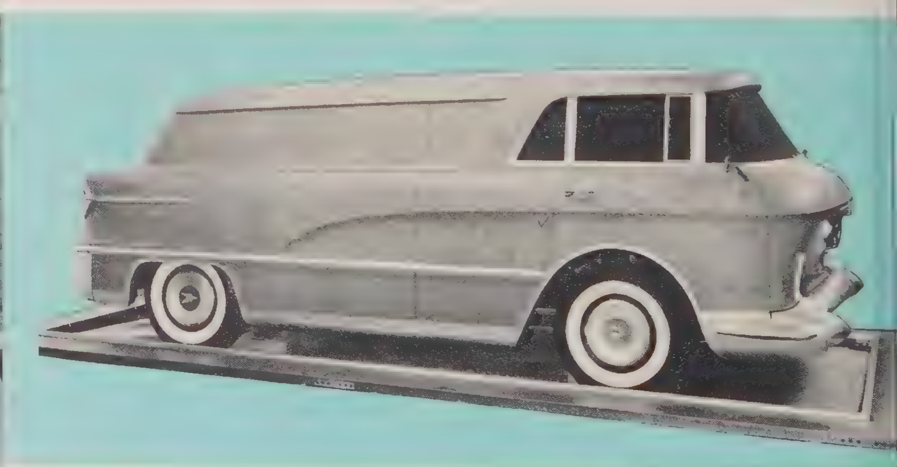


Fig. 6—During the development of the full-size clay model of L'Universelle, refinements of vario exterior components were made (left) until a final exterior surface was fixed (above). This allowed th next step in the process to take place—fabrication of the prototype body of the truck out of metal and gla fiber.

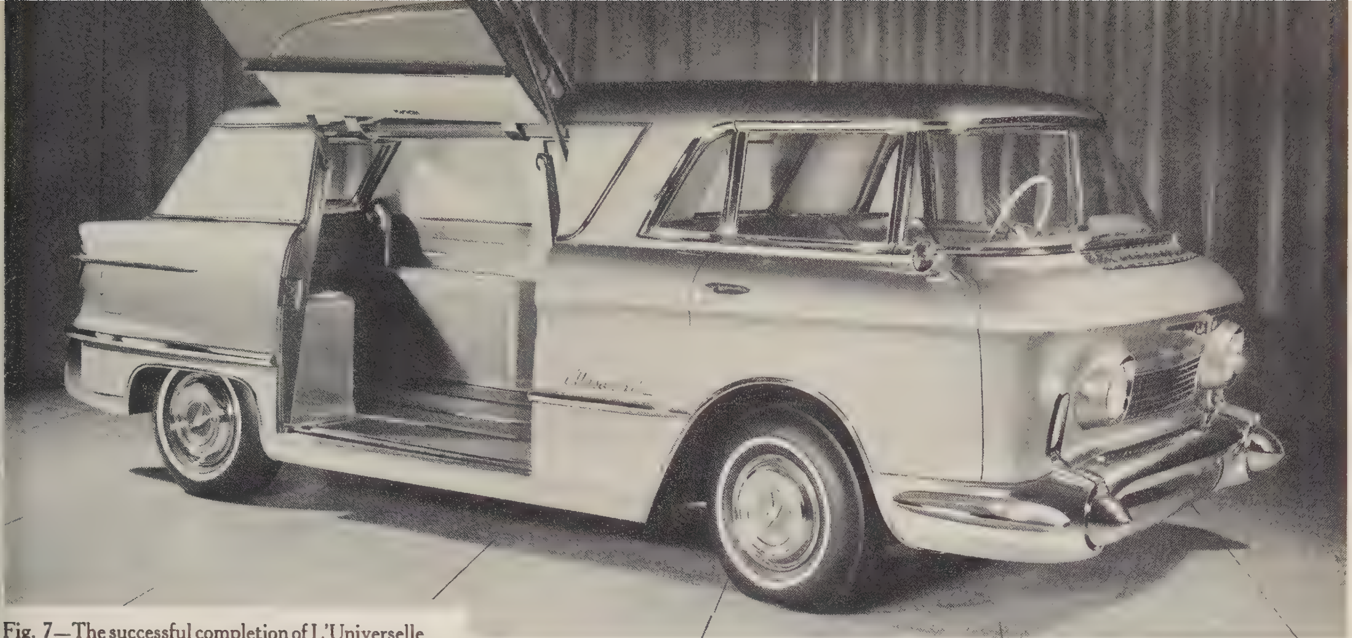


Fig. 7—The successful completion of L'Universelle panel delivery all-purpose vehicle for showing in the 1955 GM Motorama typifies the teamwork approach used in designing such a "dream" vehicle. The idea, basic design, and appearance were conceived by the Styling Staff. The GM Engineering Staff drew up specific engineering proposals for the chassis, engine, and transmission components. The chassis design and construction was completed by GMC Truck and Coach Division. The complete fabrication of the vehicle was then made by the Styling Staff.

the chassis. GMC Truck and Coach Division indicated an interest in making a contribution to the project.

The drawings prepared by GM Engineering Staff did not specify details. Only general recommendations were made for a course of action and left the detailed design to the builder of the chassis.

The task facing GMC Truck and Coach was to design and build a chassis along the lines recommended by the Engineering Staff, to do it quickly, and to provide the benefit of its extensive experience in truck manufacturing.

There was little time for detailed design work. No attempt was made then to design for production. Just enough preliminary development and layout drawings were done to enable the GMC Truck and Coach experimental shop to build a chassis which would embody the principles conceived by Styling and developed by Engineering Staff.

Within eight weeks GMC Truck and Coach had designed and constructed an experimental chassis which was suitable in every way for the proposed usage (Fig. 5).

In the process a number of changes were made. The radiator core, at first planned for the nose of the cab, was moved to the engine compartment and placed above the engine at an angle. A grille opening was cut in the roof panel immediately above the radiator and engine. A special fan-pulley drive was devised to permit the new radiator location. In the steering linkage, bevel gears replaced the universal couplings originally specified.

At this time Styling had practically completed the full-size clay model (Fig. 6) of L'Universelle. The front end had been altered following the decision to move the radiator core. Provision was made for the new steering linkage. The exterior design was fixed.

Now preparations were made to fabricate the prototype body of L'Universelle out of metal and glass fiber. The Styling Staff Engineering Department began the design of principal structural members, which were also to be of glass fiber. Wood patterns and forms for hammering metal parts were designed for metal parts, such as grille, bumpers, moldings, and instrument panels. Shop orders were written to the plaster, wood, metal, and glass fiber shops.

The chassis arrived in the Styling Metal Shop around the first of November 1954. Meanwhile, plaster crews were casting the clay surface of L'Universelle and making the molds which would be the basis for the construction of the glass fiber body. Bronze metal castings were being made from mahogany patterns and hammered metal parts were formed over precision wood forms.

As quickly as the glass fiber structural parts were completed, they were bolted to the chassis, and the process of assembling the "dream truck" had begun. After all parts were hand-fitted into place, the metal trim parts were removed for chrome plating and the body surfaces were painted. Inside the "dream truck" the hard and soft trim were installed. The final assembly, which took place in the Styling Staff's Metal Shop, marked the successful completion of the design and fabrication of L'Universelle (Fig. 7).

Summary

The creation of L'Universelle—from its initial conception to the final "dream truck" shown before GM Motorama audiences in 1955—was the result of combined teamwork on the part of stylists and engineers. Successful attainment of the three specific goals established at the outset of L'Universelle's development—maximum load volume, greater load accessibility, and passenger car comfort and visibility—was made possible only after many people had played a part in developing sound engineering recommendations for its engine, chassis, and transmission components, in addition to developing an overall appearance which would be aesthetically pleasing.

Acknowledgement

The authors acknowledge the contributions made by Maurice A. Thorne, head of Vehicle Development, General Motors Engineering Staff, who directed the engineering group proposing initial chassis design, and Gil Roddewig, head of experimental engineering, GMC Truck and Coach Division, who directed the final design and construction phase of L'Universelle panel delivery truck's chassis.

Contributors to May-June 1956 Issue of GENERAL MOTORS ENGINEERING JOURNAL

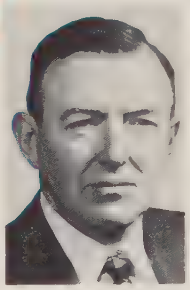
WILLIAM G. AGNEW, contributor of "The Application of Radiation Techniques to Engine Combustion Studies," is a senior research engineer in the Fuels and Lubricants Department of General Motors Research Staff. Application of radiation techniques to combustion research, preflame reaction mechanisms, and measurements of temperature are among his current projects.

Mr. Agnew received the B.S.M.E. degree from Purdue University in 1948. He then undertook graduate work and received the M.S.M.E. in 1950 and, two years later, the Ph.D. in mechanical engineering. While studying for his doctorate, Mr. Agnew worked as a research assistant at the University.

Shortly after receiving the Ph.D. degree, Mr. Agnew joined the Organic Chemistry Department of the General Motors Research Laboratories Division. (The Research Laboratories Division was renamed the Research Staff in 1955.) He had previously been employed as a summer student at the Research Laboratories Division in 1947. Before assuming his present position and duties in November 1953, Mr. Agnew worked on the investigation of the effects of atmospheric conditions on engine performance and studies dealing with the formation of induction system deposits.

Mr. Agnew has co-authored several published papers on spectographic combustion studies His technical affiliations include the Society of Automotive Engineers and the Coordinating Research Council's Coordinating Fuel Research advisory group on instantaneous temperature measurement. He also is a member of Sigma Xi and Pi Tau Sigma, honorary societies.

From 1944 to 1946 Mr. Agnew served in the U.S. Army. After his discharge from service, he worked as a civilian with the Engineers Corps at the Los Alamos Laboratory, Manhattan District, New Mexico.



ALFRED L. BOEGEHOLD, co-contributor of "Research Staff Facilities," was named assistant to the vice president in charge of Research Staff in January 1952.

Mr. Boegehold joined General Motors Research Staff in 1920 and five years later was named head of the Staff's Metallurgical Engineering Department. He was graduated from Cornell University with a mechanical engineering degree in 1915.

His contributions encompass many phases of metallurgical engineering, ranging from improving the properties of metals through changes in composition and internal grain structure to the development of new foundry and metal processing techniques. His pioneer work with powdered metals led to the development of oilless bearings.

By devising a test which correlates a particular steel's strength with the degree to which it is hardened under a standard quenching treatment, he established a new concept for specifying steels which permits metallurgists to substitute low alloy steels for steels containing relatively large amounts of strategic materials. Since World War II Mr. Boegehold's work has contributed to the development of Aldip, an aluminum dipping process which permits ordinary steel to replace alloy steels for many applications where high temperature corrosion is a problem, and GMR-235, a super alloy used for turbine buckets in all Allison jet engines.

Mr. Boegehold's work has resulted in the grant of patents covering his accom-

plishments in these various fields, as well as others in the fields of molding, casting brazing, and heat treating techniques.

Mr. Boegehold was an executive committee member of the Iron and Steel Institute of the American Institute of Mining and Metallurgical Engineers in 1943 and 1948. He is a life member of the American Foundrymen's Society and was named winner of the Society's J. H. Whiting prize in 1929 and the J. H. Whiting Gold Medal in 1942 for his work on cast iron. He is also a life member of the American Society for Metals, of which he was president in 1947, having served as an officer in various positions since 1937. He received the A.S.M. Gold Medal in 1955 "in recognition of his great versatility in

applying science to the metal industry." He is a member of the S.A.E. and was vice president in charge of the Engineering Materials Activity in 1954.

JOHN M. CAMPBELL, co-contributor of "Research Staff Facilities," is technical director of the Research Staff.

After being graduated from Massachusetts Institute of Technology in 1925, he joined the Fuel Section of the Research Staff. From 1926 to 1942 he was concerned principally with the development of the relationship between molecular structure of hydrocarbons and their knocking characteristics in internal combustion engines, leading to the development of today's high octane gasolines.

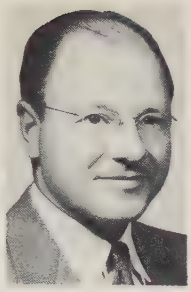
In 1942 Mr. Campbell was transferred to the GM Proving Ground to work on military projects. His other wartime activities included membership on the War Advisory Committee, Coordinating Research Council. He returned to the Research Staff in 1944, and in 1947 he was appointed head of the Organic Chemistry Department, where he was concerned with fuel utilization problems in internal combustion engines. His work has resulted in a number of patents on processes for the utilization of fuels.

Mr. Campbell became assistant technical director of the Research Staff in 1952, administrative director in 1953, and assumed his present position in August 1954.

Mr. Campbell has served as vice president for Fuels and Lubricants of the S.A.E. and is currently serving as a director of the American Society for Testing Materials.

With the Coordinating Research Council Mr. Campbell served for many years as chairman of the Motor Fuels Division. In 1954 he was appointed chairman of the Vehicle Combustion Products Subcommittee of the Automobile Manufacturers Association. This committee was established for the purpose of studying the effect of motor vehicle exhaust gases on air pollution in cities.

Mr. Campbell is also a member of the Technical Advisory Panel on Fuels and Lubricants, Department of Defense, as well as many technical societies.



DARL F. CARIS, co-contributor of "Research Studies on Automotive Engine Fuel Economy," is head of the Automotive Engines Department, General Motors Research Staff. He has been engaged in the development of high-compression engines for a number of years.

Mr. Caris began his engineering career in General Motors in 1926 as an electrical engineer with the Research Staff Electrical Section. In 1931 he became a project engineer in the same department, specializing in development of instrumentation for measuring vibration, sound, acceleration, torque, and engine pressure. Mr. Caris was named head of Mechanical Engineering Department No. 4 in 1938, and in this capacity he was engaged primarily in research on internal combustion engine development, including two-cycle engines. During World War II he devoted his efforts to the development of gyroscope controls for Army Air Forces aircraft. Since that time the Department's responsibilities have expanded, and the name recently was changed to Automotive Engines Department.

The University of Michigan granted Mr. Caris the B.S. degree in electrical engineering in 1926 and in 1932 awarded him the professional degree of electrical engineer.

He has presented papers to the Society of Automotive Engineers and other technical societies covering many aspects of high compression engine development and engine instrumentation. In addition, he has contributed numerous articles to technical magazines.

Patents in the oscillograph, engine blower control, and gyroscopic fields have resulted from his laboratory work.

Mr. Caris is a member of the American Physical Society, the S.A.E., and the Engineering Society of Detroit.

Contributors' backgrounds vary greatly in detail but each has achieved a technical responsibility in the field in which he writes.

CHARLES A. CHAYNE, contributor of "Product Engineering in General Motors," has served since January 1951 as vice president of General Motors in charge of the Engineering Staff. His office directs engineering groups which perform engineering services of benefit to General Motors as a whole. More than one-third of this work force of some 2,600 engineering and technical personnel is concentrated at the Technical Center. Mr. Chayne's office also coordinates the engineering efforts of the more than forty separate engineering organizations within General Motors in which more than 25,000 employes are engaged in engineering developmental work.

Mr. Chayne joined Buick Motor Division in January 1930 and assumed charge of the engine division. He was appointed assistant chief engineer in 1933 and became chief engineer in 1936, a position he retained until becoming a GM vice president.

Notable successful developmental projects during Mr. Chayne's period at Buick included the straight-eight engine (predecessor of the present 90° V-8 engine), all-coil-spring suspension, automatic transmissions, and many other automotive advances. He was a leader in gaining national acceptance for E-Z Eye glass and the horn rim. His laboratory work resulted in eight patents covering steering linkages, spring suspension, frames, transmission controls, and valve mechanism temperature regulators. Other applications are pending.

Mr. Chayne started his career as a junior mechanical engineer in 1919 with the National Advisory Committee for Aeronautics. After one year in the N.A.C.A. laboratories he became a mechanical engineering instructor at Massachusetts Institute of Technology for six years, then becoming an experimental engineer with the Lycoming Manufacturing Company. His first automotive engineering work was with the Marmon Automobile Company as a design engineer.

Mr. Chayne earned the B.S.M.E. degree at M.I.T. in 1919 and holds a qualifying degree from Harvard University. His society affiliations include the S.A.E. and the American Society of

Mechanical Engineers. He is also a member of the Pi Tau Sigma, honorary engineering society.

JOHN J. CRONIN, contributor of "Manufacturing in General Motors," is vice president of General Motors in charge of the Manufacturing Staff. He was appointed to this post in 1952, after more than 30 years' experience with the Fisher Body Division of GM, where he rose to the position of vice president and general manager.

The Manufacturing Staff acts as an advisory body to the GM Divisions on operations in connection with manufacturing facilities and processes. In addition, this Staff coordinates the planning for the inflow of basic materials; handles the purchase, lease, and disposition of real estate for the Divisions; and assists in matters involving construction and alteration.

Mr. Cronin began his career in 1918 in Fisher Body's Material Department, advancing by steps to the Cost Department as a cost clerk and to the Engineering Department as a production engineer. Later he became supervisor of production standards in this same Department. In 1934 he was appointed assistant general factory manager in charge of assembly plants and seven years later assumed the position of general factory manager. In April 1941 Mr. Cronin became director of industrial relations and in the fall of 1944 was promoted to general industrial relations director. He was named general manufacturing manager of Fisher Body Division in December 1945.

Mr. Cronin was elected a vice president of General Motors in 1948 and was named general manager of Fisher Body Division, where he served until appointment to his present position.

The University of Detroit granted Mr. Cronin the A.B. degree in 1915 and awarded him the honorary Doctor of Laws degree in 1951.

JOHN DOLZA, co-contributor of "A Product Engineering Study: Design of an Axial-Type Refrigeration Compressor," is engineer in charge of the Power Development Section of General Motors Engineering Staff. In this capacity Mr. Dolza supervises his group in contributing various details of engine design to the General Motors car Divisions as well as developmental work on complete engines for the Armed Forces and for future consideration by the GM Divisions. His activities also include developmental work on automotive air conditioning refrigeration compressors, of which he writes.

Mr. Dolza's career with General Motors began in 1927 when he was employed as a draftsman for Buick Motor Division, Flint, Michigan. Successive promotions led him to the position of assistant chief engineer. In 1940 Mr. Dolza was transferred to Allison Division, Indianapolis, Indiana, where he was engaged as consulting engineer on special assignments. In 1945 he was transferred to the Power Development Section of the Engineering Staff and assumed his present position.

Mr. Dolza's previous major projects include developmental work on automatic controls for aircraft engines, aircraft turbo automatic controls, pilot automatic controls, lubrication systems for high-altitude aircraft engines, and turbo-prop engines and their related controls.

Mr. Dolza received his master's degree in both electrical engineering and mechanical engineering from the Polytechnic Institute, Turin, Italy, in 1926. While at the Institute he designed the school's Altitude Laboratory.

Mr. Dolza's technical affiliations include membership in the S.A.E. He received the S.A.E.'s Manley Award in 1942. His work has resulted in the grant of 22 patents.

HARLEY J. EARL, contributor of "Styling in General Motors" and co-contributor of "Development of a New Concept in Panel Delivery Truck Design," is vice president of General Motors in charge of the Styling Staff.

In 1927 Mr. Earl was appointed director of a newly formed department of General Motors, the Art and Color Section, renamed the Styling Section in 1937 and now the Styling Staff. In addition to the supervision of the designing of motor cars for General Motors, Mr. Earl's work embraces the designing of product exhibits, experimental cars, streamlined trains, ranges, washing machines, electric fans, batteries, radios, and most other appliances and accessories manufactured by General Motors.

Originally from California, Mr. Earl was initiated into the field of automotive styling at an early age when he received training in designing and drafting, as well as practical experience, in the Earl Carriage Works, his father's company in Los Angeles.

After taking courses in arts and sciences at Leland Stanford University, Mr. Earl returned to Los Angeles as director of an extensive custom body shop at the Don Lee Corporation, which had purchased the Earl Carriage Works. This shop specialized in different types of designs

for open and closed cars on foreign and American chassis, and it was at this time that Mr. Earl's reputation as an automobile designer grew.

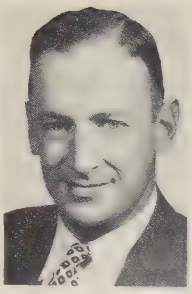
Subsequently Mr. Earl was retained as a consultant with Cadillac Motor Car Division where he was responsible for the designing of the original LaSalle and the redesigning of the Cadillac motor cars. At General Motors his reputation has grown until today he is recognized as one of the foremost leaders in the field of automotive styling.

RODGER J. EMMERT, contributor of "Manufacturing Staff Facilities," is executive in charge of Facilities and Processes activities on the General Motors Manufacturing Staff. Facilities and Processes activities include a number of staff organizations having responsibilities for manufacturing development, production engineering, work standards and methods engineering, power, communications, and air transport.

Mr. Emmert was appointed to his present post in 1948 following a period of more than twenty years spent in management responsibilities at several GM Divisions. His General Motors employment began in 1919 when he joined the Remy Electric Division as an electrical engineer. Six years later he became tool engineer at the same Division.

He transferred to Dayton, Ohio, in 1927 as factory manager of the Delco Division of Delco-Remy Corporation and two years later was named president and general manager of the Delco Products Corporation, now a General Motors Division. In 1930 he was transferred to the presidency of General Motors Radio Corporation in Dayton. Following two years at this post, he transferred to Pontiac, Michigan, to become factory manager of the Yellow Truck & Coach Manufacturing Corporation (now known as GMC Truck & Coach Division). He continued in this capacity for 16 years until appointment to his present position.

Mr. Emmert received the B.S.E.E. degree from Case School of Applied Science in 1916. He has been elected to Tau Beta Pi and Sigma Xi, honorary fraternities, and he is a member of the S.A.E.



GLEN R. FITZGERALD, co-contributor of "Production, Methods Engineers Join in Advancing Manufacturing Technology," has been director of the Process Development Section, General Motors Manufacturing Staff, since 1953. This Section develops and designs equipment and techniques for manufacture of end products.

Mr. Fitzgerald was graduated in industrial engineering from General Motors Institute, Flint, Michigan, in 1938, having been sponsored as a co-op student by AC Spark Plug Division.

Upon graduation Mr. Fitzgerald joined AC Spark Plug as a junior process engineer, assisting in production tryout of new materials. In 1940 he took charge of processing for a 50-caliber machine gun on which process changes were made such as barrel finishing of certain small parts rather than hand de-burring, applications of resistance heating to riveting, and development of a fast cleaning process after test firing.

In 1942 Mr. Fitzgerald became assistant methods supervisor for AC's two plants and devoted part of his time to administration of a new employe suggestion plan. He also taught methods engineering to supervisors. From 1945 to 1950 he was assistant chief die cast engineer heading a group working toward standardization of die casting techniques to enable the die maker to work from drawings. Mr. Fitzgerald then became production engineer for the instrument division of AC for a brief period before assuming night superintendency of the spark plug manufacturing operation. In 1951 he became assistant chief manufacturing development engineer and made contributions to special automatic assembly machines which have since become standard. He was assistant master mechanic at the time he was appointed to his present Central Office position.

Mr. Fitzgerald has been a member of the American Electroplaters Society and the American Society for Metals. He is currently active in the American Ordnance Association, the American Society of Tool Engineers, and the Engineering Society of Detroit, and he is assistant vice chairman of the production activity

of the S.A.E. He is a registered professional engineer in the State of Michigan.

PHILIP L. FRANCIS, co-contributor of "A Product Engineering Study: Design of an Axial-Type Refrigeration Compressor," is a project engineer in the Power Development Section of General Motors Engineering Staff.

Mr. Francis joined General Motors in March 1943 as a design engineer with Fisher Body Division, Aircraft Development Section. Here he designed much of the flight test instrumentation used on the B-19 airplane. He was then transferred to the XP75 project as a contact engineer between Detroit and Cleveland, where the planes were being built.

In 1945 he served with the United States Maritime Service as an engine instructor. The courses taught by Mr. Francis were to prepare the men to take and pass Coast Guard examinations for various merchant ship engine room licenses. After leaving the service, he was employed at Pontiac Motor Division from 1945 to 1951 where his work centered around engine development. Upon joining General Motors Engineering Staff in 1951, Mr. Francis continued his work on the development of automotive engines. He is presently engaged in the basic design, development, and testing of refrigeration and air compressors and also work on superchargers.

Previous to his General Motors employment Mr. Francis worked at Square D Electric Company and Tucker Aircraft Company, where he was engaged in aircraft developmental work. He is a member of the S.A.E.

DR. LAWRENCE R. HAFSTAD, contributor of "Research in General Motors," is vice president of General Motors in charge of Research Staff. He was graduated from the University of Minnesota in 1926 with a bachelor's degree in electrical engineering. He continued at Minnesota as a graduate student in physics for two more years and then joined the staff of the Carnegie Institution of Washington, D. C. He continued advanced studies at Johns Hopkins University where he was awarded the Ph.D. in physics in 1933.

From 1928 to 1946 Dr. Hafstad remained on the staff of the Carnegie Institution as a research physicist. He was assigned to the staff of the Applied Physics Laboratory of Johns Hopkins at Silver Spring, Maryland, from 1942 to 1945 for war work, becoming assistant director in 1943 and director of Research in 1945. In 1947 he was named executive secretary of the Research and Development Board, Office of the Secretary of Defense. In addition, he served as professor of applied physics at Johns Hopkins from 1947 to 1954 and director of the Johns Hopkins Institute for Cooperative Research at Baltimore, Maryland, from 1947 to 1949.

From 1949 to 1955 he served as the first director of the U. S. Atomic Energy Commission's Reactor Development Division, Washington, D. C., being responsible for the developmental programs for nuclear powered submarines and aircraft, as well as for civilian atomic power. From 1949 to 1951 Dr. Hafstad carried a Presidential appointment as chairman of the Interdepartmental Committee on Scientific Research and Development at Washington.

Dr. Hafstad resigned in January 1955 to take a position as director of the Chase Manhattan Bank's Atomic Energy Division at New York City. In September of that year he succeeded Charles L. McCuen as General Motors vice president in charge of Research Staff.

Dr. Hafstad has done original scientific work in the fields of ionosphere studies, radioactivity, and artificial atomic disintegration.

Dr. Hafstad is a member of several technical societies and honorary fraternities including Sigma Xi, Tau Beta Pi, and Eta Kappa Nu.

FRED T. HALL, co-contributor of "A Manufacturing Development: the Gyrofinishing Process for Polishing Metal Surfaces," is a project engineer in the Process Development Section of the General Motors Manufacturing Staff.

Mr. Hall was originally employed by General Motors at GMC Truck & Coach Division, Pontiac, Michigan, in February 1941 as a junior draftsman in the Engineering Department. In the fall of the same year he entered General Motors Institute, Flint, Michigan, as an engineering cooperative student sponsored by GMC Truck & Coach.

From 1942 through 1946 he served with the United States Air Force and Army Ordnance. Upon his discharge from military service, Mr. Hall returned to GMC Truck & Coach Division as an engineering cooperative student and was graduated from General Motors Institute in 1949.

From 1949 to 1951 he worked in the Truck Engineering Department at GMC Truck & Coach on GM Proving Ground test results and vehicle specifications. In March of 1951 he was transferred to the Process Development Section of the Manufacturing Staff, and in 1953 he was promoted to his present position as project engineer.

Mr. Hall's current projects include the development of manufacturing processes, machines, and tooling concerning finishing and deburring. It is from this work that his paper on the Gyrofinishing process is drawn.

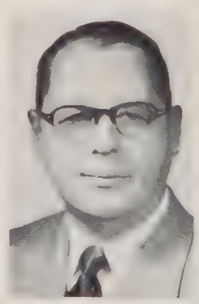
Mr. Hall is a member of the American Society of Tool Engineers.

CHARLES M. JORDAN, co-contributor of "Development of a New Concept in Panel Delivery Truck Design," is chief designer, Special Studio No. 4 of the General Motors Styling Staff.

After receiving the B.S.M.E. degree from Massachusetts Institute of Technology in 1949, Mr. Jordan joined General Motors Styling Staff as a junior designer. In 1950 he was promoted to designer and in 1952 to senior designer.

From June 1952 to June 1953 Mr. Jordan served as First Lieutenant with the United States Air Force. Upon his separation, he rejoined the Styling Staff as assistant chief designer in the Truck Studio where his work provided the basis for his contribution to the paper in this issue on L'Universelle. In October 1954 Mr. Jordan was promoted to chief designer in charge of the Euclid-Electro-Motive Studio where he directed the styling of the Euclid twin powered TC-12 crawler tractor and the GM light-weight Aerotrain.

Mr. Jordan has received an award as Life Member of the California Scholastic Federation. In 1947 he won first prize in Fisher Body Craftsman's Guild competition and was elected president of the Guild in 1949.



OLIVER K. KELLEY, contributor of "Operating Principles and Applications of the Fluid Coupling and Torque Converter to Automatic Transmissions," has been engineer in charge of the Transmission Development Section of the Engineering Staff since 1940.

After obtaining the B.S. and M.E. degrees in mechanical engineering from Chicago Technical College in 1925 and taking special courses in automotive engineering at Massachusetts Institute of Technology in 1926 and 1927, Mr. Kelley joined General Motors as a draftsman with Cadillac Motor Car Division.

In 1929 he was transferred to GMC Truck and Coach Division as a design engineer. A short time later he was made special assignment engineer serving until 1936. He was then transferred to the GM Engineering Staff to join the group assigned to automatic transmission development.

In 1939 Mr. Kelley was made assistant chief engineer of the Detroit Transmission Division, at that time newly organized to produce the Hydra-Matic automatic transmission, and in 1940 he was assigned to his present position on the Engineering Staff.

Twenty-four patents have been granted as a result of Mr. Kelley's work in the development of automatic transmissions, and he is the author of several technical papers on this subject.

Mr. Kelley is a member of the S.A.E., the Engineering Society of Detroit, and the American Ordnance Association. He served as the wartime chairman of the S.A.E. Transmission Committee on Captured Enemy Equipment and is presently the chairman of the S.A.E. Hydrodynamic Drive and Transmission Committee.

Mr. Kelley is a recipient of the National Association of Manufacturers Award of "Modern Pioneer" and the S.A.E. Certificate of Appreciation for outstanding service.

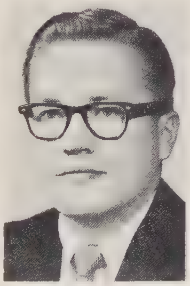
ERVINE E. KLEIN,
co-contributor of "Unique Architectural Elements of the GM Technical Center," is a contact engineer in the Engineering Department of Argonaut Realty Division, an activity of the General Motors Manufacturing Staff.

Mr. Klein joined General Motors in 1946 as an architectural engineer with Argonaut Realty. One of his early accomplishments was the remodeling and reconversion of GM's Cleveland, Ohio, plant from the production of bombers for the Air Force to a facility for the manufacture of tanks for the Army.

In 1947 Mr. Klein was promoted to senior architectural engineer, and shortly thereafter he assumed the responsibility for coordinating the planning, design, and construction of a Diesel locomotive plant at London, Ontario, for General Motors Diesel Limited.

Mr. Klein assumed his present position as contact engineer for Argonaut in 1950 and later that year was assigned to work on the Technical Center project. Since then he has been continuously responsible for coordinating much of the work of the architects, architectural engineers, and field supervisors who are responsible for the planning, design, and construction of the Technical Center Buildings, of which he writes in this issue.

After studying architecture at the University of Nebraska, Mr. Klein entered the U.S. Army, Corps of Engineers, in 1941. While in the service he served in both the South Pacific and European Theaters as an airfield construction and maintenance officer. He was separated in 1945 with the rank of First Lieutenant.



DONALD P. KOISTINEN,
contributor of "A Discussion of the Phase Composition of Ball Bearing Steel and Its Measurement," is a research physicist in the Physics and Instrumentation Department of General Motors Research Staff.

Mr. Koistinen has worked on the magnetic properties of ferrous alloys and has studied the corrosion products of steel using X-ray diffraction techniques. Currently he is concerned with the development of X-ray diffraction techniques for measuring the phase composition and residual stresses in steel and the application of these techniques to fundamental metallurgical problems.

After receiving the B.S. degree in physics from the University of Michigan in 1952, Mr. Koistinen joined the Physics and Instrumentation Department of the GM Research Staff as a junior physicist. He continued in that capacity until promotion to his present position in 1955. During World War II Mr. Koistinen served in the United States Navy from 1945 to 1947 as an Electronic Technician's Mate, Second Class, teaching elementary electronics and radio materiel.

He has collaborated on the preparation of two published papers, "Effects of Sample Surface and X-ray Diffraction Camera Geometry on the Determination of Retained Austenite in Hardened Steels" for the *Journal of Metals*, November 1953, and "Some Effects of Metal Removal and Heat Treatment on the Surfaces of Hardened Steels" in the *Transactions of the American Society for Metals* for 1956.

Mr. Koistinen is a member of the Michigan Chapter of the American Crystallographic Association serving as vice-chairman for 1955-1956.

WILLIAM F. LANGE,
co-contributor of "Development of a New Concept in Panel Delivery Truck Design," is chief designer in the GMC Truck Studio of the General Motors Styling Staff.

Mr. Lange's General

Motors employment began in 1937 when he was a designer in the Cadillac Studio of the Styling Staff. From 1938 to 1941 he worked as a designer in the Pontiac Studio. The next year he became a graphic engineer in the Production Illustration Department and then transferred to GM aircraft development, performing inspection of parts in the Experimental Section. From 1943 to 1944 he worked as a graphic engineer in Production Illustration again and the next year served as assistant supervisor, Hand Book Section, Fisher Aircraft, Cleveland, Ohio. In 1946 Mr. Lange rejoined GM Styling, Overseas Studio, becoming assistant supervisor the next year. From 1948 to 1954 he was chief designer of the Orientation and Experimental Design Studio. In 1955 he was appointed to his present position.

Among the recent styling problems of which Mr. Lange has had charge are the design programs for the post-war Opel Kapitan cars, the full-size design model of L'Universelle, of which he writes, and the designing of a special sight-seeing bus. In addition to his duties as chief designer in the GMC Truck and Coach Studio, Mr. Lange also has charge of a special project in the Euclid Design Studio.

Mr. Lange attended Cleveland Art School and John Huntingdon in Cleveland, Ohio. During World War II he studied aircraft drafting and industrial supervision and inspection at Wayne University, Detroit, Michigan.

ROBERT D. McLANDRESS, co-contributor of "Production, Methods Engineers Join in Advancing Manufacturing Technology," serves as director of the Work Standards and Methods Engineering Section of the General Motors Manufacturing Staff.

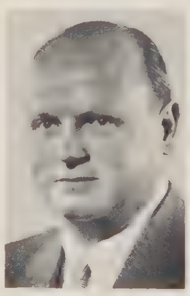
Directly after receiving the B.S. degree from Michigan State College in 1927, Mr. McLandress joined the Cadillac Motor Car Division as a clerk in the Accounting Department. In January 1928 he transferred to the Central Foundry Division as assistant employment manager and for the next 10 years remained with this Division serving as safety engineer, supervisor of work standards and methods engineering, and production manager.

In August 1938 Mr. McLandress transferred from Central Foundry Division to become a member of the executive training staff at General Motors Institute for the next two years. From September 1940 to October 1942 he was employed by the Bendix Aviation Corporation.

Mr. McLandress joined Saginaw Steering Gear Division in October 1942 as supervisor of work standards and methods engineering and later became personnel director. He was transferred to his present position on the Manufacturing Staff, Central Office, in February 1947.

Mr. McLandress is the author of a number of papers among which are: "The Role of Industrial Engineering in Cost Reduction," "Machine Tools and Men," "Manpower Utilization," and "Organization and Coordination of Industrial Engineering Functions in a Large Corporation." He contributed a previous paper to the GENERAL MOTORS ENGINEERING JOURNAL, Vol. 1, No. 3, entitled, "Methods Engineering for More Effective and Economical Use of Manpower."

He is a member of the Engineering Society of Detroit, the Industrial Management Society, and the Society for the Advancement of Management.



WILLIAM L. MITCHELL, contributor of "Styling Staff Facilities," was named director of the General Motors Styling Staff in May 1954.

Mr. Mitchell attended Carnegie Institute of Technology in Pittsburgh, Pennsylvania, and took art training at the Art Students League. He joined General Motors in 1935 as a designer with the Styling Staff. In 1937 he was appointed chief designer of the Cadillac Studio.

From 1942 to 1945 Mr. Mitchell served as a Lieutenant with the United States Navy. Upon separation from the service he returned to his former position in the Cadillac Studio. In July 1953 he became assistant director of the Staff and subsequently assumed his present position in 1954.

RALPH A. RICHARDSON, co-contributor of "Research Staff Facilities," is head of the Administrative Engineering Department of the Research Staff. His Department provides engineering services and correlates work of the Staff with engineering departments of GM manufacturing Divisions and Central Office Staff operations.

Mr. Richardson was graduated from the University of Minnesota in 1927 with the B.S. degree in mechanical engineering. At this time he joined General Motors as a junior engineer at AC Spark Plug Division in Flint, Michigan, where he worked as a tool and die designer. In the fall of 1927 he was transferred to the Research Laboratories Division (now the Research Staff) and assigned to the Technical Data Department. He became assistant department head in 1932 and four years later was named head of the Department. The Department is now the Administrative Engineering Department. From January 1943 to January 1946 he served in the Navy as a specialist electronics officer and attained the rank of Lieutenant Commander.

Mr. Richardson has been a frequent contributor to technical literature. A series of engineering booklets which he prepared for his Department now is used in educational institutions, training courses, and engineering public relations activities. He contributed to the automotive section of Kent's *Mechanical Engineers' Handbook* and was co-author of a book on the automotive industry published by the Encyclopedia Britannica.

Mr. Richardson's technical affiliations include membership in the S.A.E. and the Engineering Society of Detroit.

GEORGE R. SQUIBB, co-contributor of "A Manufacturing Development: The Gyrofinishing Process for Polishing Metal Surfaces," is chief project engineer in the Process Development Section, General Motors Manufacturing Staff.

He joined the Process Development Section in 1949 as a senior project engi-

neer and one year later was advanced to his present position, in which capacity he supervises project engineering for the Section. Previously Mr. Squibb had been associated for 15 years with the Cincinnati Milling Machine Company, Cincinnati, Ohio, where he was engaged in engineering developmental work on machine tools. He also served for one year as chief engineer with the Detroit Broach Company, Detroit, Michigan, before joining General Motors.

Several patents have been granted as a result of his work in the field of milling machines, broaching machines, broaching tools, and grinding machines. In the same field he has delivered numerous talks and had several papers published.

In 1933 Mr. Squibb was granted the degrees of B.S.M.E. and B.S.A.E. from the University of Michigan where he was elected to Tau Beta Pi, Vulcans, and Triangle, honorary societies. He is a registered professional engineer in the States of Ohio and Michigan.

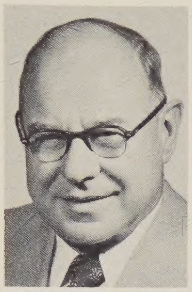
He is a member of the Engineering Society of Detroit and the American Society of Tool Engineers, having served as chairman of the A.S.T.E. Cincinnati Chapter in 1947.

WILLIAM K. STEINHAGEN, co-contributor of "A Product Engineering Study: Design of an Axial-Type Refrigeration Compressor," has been a staff engineer in the Power Development Section of General Motors Engineering Staff since 1952. He is currently working on advanced refrigeration equipment and automotive engine components.

After a tour of duty with the Army, from which he was separated in 1946 with the rank of Captain, Mr. Steinhagen was graduated from the University of Michigan with the B.S.E. degree in 1947 and a year later was awarded the M.S.E. degree from the same university.

Upon graduation Mr. Steinhagen joined the Engineering Staff's Power Development Section as a junior engineer. In 1949 he became a design engineer and in 1951 a senior project engineer. Among his projects were the development of air-cooled military and commercial engines, turbo-prop engine controls, and automotive air conditioning.

Mr. Steinhagen is a member of the S.A.E., the American Society of Mechanical Engineers, the American Society of Refrigerating Engineers, and the Engineering Society of Detroit. He is also a member of the Heating, Cooling, and Ventilation Sub-Committee of the GM General Technical Committee.



FREDERICK G. TYKLE, co-contributor of "Unique Architectural Elements of the GM Technical Center," is the executive in charge of Real Estate of the General Motors Manufacturing Staff. The Real Estate activities include Argonaut Realty Division, Technical Center Service Section, General Motors Building Division, and Office Services Section.

Mr. Tykle joined General Motors as an engineer in the Plant Engineering Department of Delco-Remy Division, Anderson, Indiana, in 1927. In 1939 he became assistant plant superintendent. He then transferred to Allison Division as plant engineer in January 1941 and subsequently became director of Real Estate for General Motors Manufacturing Staff in July 1945.

His position as executive in charge of Real Estate entails supervision of the acquisition of real estate and the design and construction of buildings for all Divisions of General Motors. Much of his recent activity has been directed toward the architectural development of the new General Motors Technical Center, of which he writes.

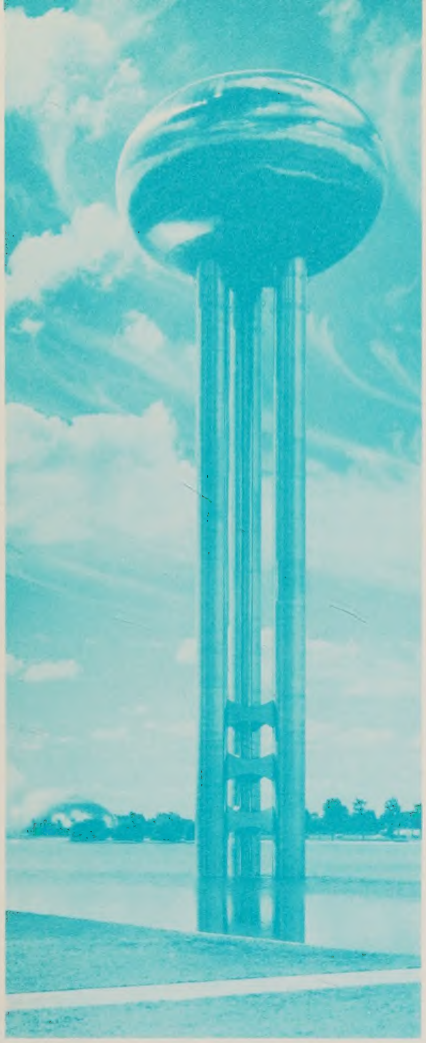
Mr. Tykle's technical affiliations include the Urban Land Institute, the American Industrial Development Council, and the Society of Industrial Realtors. He is a professional engineer in the State of Indiana.

Mr. Tykle received the bachelor of science degree in civil engineering from Purdue University in 1923, where he was a member of the honorary Contour Society. Before joining General Motors, he was employed by the State of Indiana.

Contributors' backgrounds vary greatly in detail but each has achieved a technical responsibility in the field in which he writes.

LYLE A. WALSH, contributor of "Engineering Staff Facilities," serves as manager of General Motors Engineering Staff Activities. Mr. Walsh's recent major project has been assisting with the planning and building of the Engineering Staff facilities at the new General Motors Technical Center. Mr. Walsh has been managing the Engineering Staff activities at the Technical Center since October 1950 when he transferred from the Central Offices in Detroit to the Engineering Staff's new facilities at the Technical Center.

The University of Michigan granted Mr. Walsh the B.S. degree in mechanical engineering in 1926. In July of the same year he was employed by the Oldsmobile Division in Lansing, Michigan, as a student engineer. In 1927 he was transferred to the Experimental Department



of this Division and served in various experimental and engineering capacities in the Oldsmobile and Buick Motor Divisions for the next 10 years.

In February 1937 he was transferred to the GM Central Office as assistant to Mr. O. E. Hunt, vice president in charge of the Engineering Staff. Since that time, he has served under Mr. Hunt's successors in office, Messrs. C. L. McCuen, J. M. Crawford, J. F. Gordon, and, at present, C. A. Chayne.

Mr. Walsh's technical affiliations include membership in Tau Beta Pi, honorary engineering fraternity; the S.A.E., and the Engineering Society of Detroit.

GEORGE H. WILLITS, contributor of "Some Observations from Working With Two Generations of General Motors Inventors," is director of the General Motors Patent Section, GM Engineering Staff.

Mr. Willits has a background of almost forty years in patent law work. He was educated at George Washington University, Washington, D. C. where he majored in engineering subjects and was awarded the B.A. degree. He continued his law studies and was admitted to the Bar.

Mr. Willits began regular employment at the age of 16, starting as an assistant bookkeeper at the Susquehanna Silk Mills in Sonbury, Pennsylvania. Shortly afterward he worked as a stenographer in the United States Attorney's office in Wellsboro, Pennsylvania. He then was employed for a short time in the Bureau of Naturalization and the Office of the Secretary of Labor in Washington, D. C. before joining the United States Patent Office. He served as an examiner in the Patent Office for seven years, and in 1923 he joined General Motors as a searcher in the Washington Office of the Patent Section. He was transferred in 1925 to the Central Office of the GM Patent Section in Detroit where he has served continuously since that time. He became director of the Patent Section in 1949.

FLOYD A. WYCZALEK, co-contributor of "Research Studies on Automotive Engine Fuel Economy," serves as supervisor of single cylinder engine development in the Automotive Engines Department of the General Motors Research Staff.

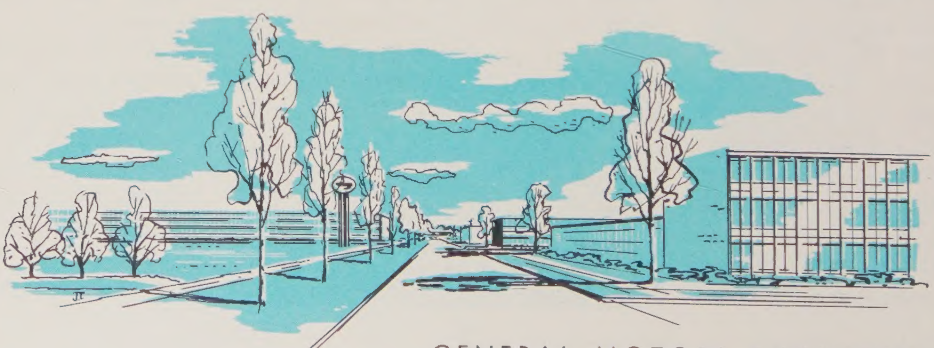
He enrolled at the General Motors Institute in Flint, Michigan in August of 1942. In September of that year he joined the United States Navy where he served until 1946 as a specialist in the field of aircraft engines. During this time he studied at Worcester Polytechnic Institute and received the B.S.M.E. degree in 1946.

In 1946 he joined General Motors as a junior research engineer on the Research Staff. In 1952 he was promoted to senior engineer and was promoted to his present position in 1954. He is currently engaged in studies to improve the efficiency of the internal combustion engine.

Mr. Wyczalek's work has resulted in the grant of one patent in the field of instruments related to automotive engines. He co-authored the paper "Mechanical Octanes for Higher Efficiency," published by the S.A.E. in June 1955.

Mr. Wyczalek is a member of Sigma Xi and Tau Beta Pi, honorary societies. His technical affiliations include The Combustion Institute, the S.A.E., and the A.S.M.E. In the latter Society, he served as program chairman of the junior section in 1953.

The GENERAL MOTORS ENGINEERING JOURNAL is a publication designed primarily for use by college and university educators in the fields of engineering and the sciences. Educators in these categories may, upon request, be placed on the mailing list to receive copies regularly. Classroom quantities also can be supplied regularly or for special purposes, upon request to the Educational Relations Section, General Motors.



Large 80 ft by 55 ft studios provide GM stylists with flexible work areas and controlled lighting.

The focal point of the Research Staff Administration Building lobby is a spiral stairway suspended by tension rods.

Process Development Section engineers designed and developed this automatic recording and computing equipment used in making efficiency tests on steering gear assemblies.

The brilliant glazed brick end-wall of the Engineering Staff Administration Building is an architectural feature repeated in most of the buildings at the Technical Center.

BACK COVER—The top photograph (by Ezra Stoller) shows the glazed brick end-wall and curtain-type side-wall construction typical of the Technical Center buildings. The lower picture (by General Motors Photographic) is a view looking south toward the Styling studios and dome-shaped auditorium. The water fountain, one of three, creates a gigantic wall of water 115 ft wide and 50 ft high, and pumps 6,000 gpm.

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